Improving Water Quality Management: Use of Earth Observations in SPARROW

Richard Alexander, John Brakebill, Anne Hoos, Molly Macauley, Richard Moore, Anne Nolin, Dale Robertson, Gregory Schwarz, Jhih-Shyang Shih, and Richard Smith

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RESOURCES FOR THE FUTURE
NASA
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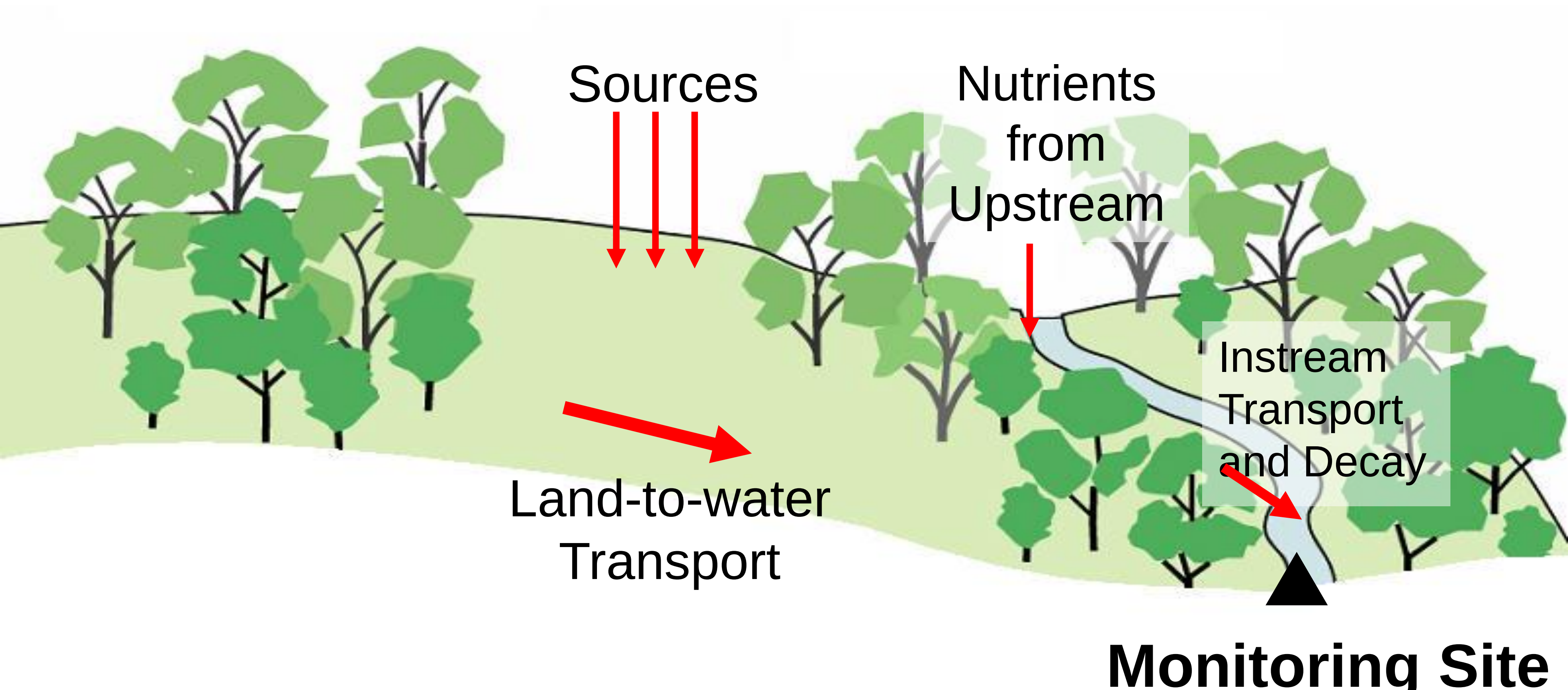
SPARROW Integrates Monitoring Data with Information on Watershed Characteristics and Nutrient Sources



Who uses SPARROW? Federal agencies; state departments of environmental quality, water quality, public health, pollution control; NGOs (TNC, etc).

The opportunity

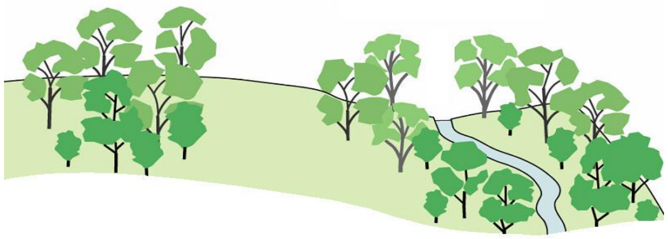
Widespread, nationwide use of SPARROW for investigating water quality (conditions, processes, and management)

***Problem*:**
Data are not readily available for regular updating (example: some data available only every five years)

***Research Question*:**
Can we do better by using MODIS data products, and if so, how much better?

****Specifically , is seasonally dynamic SPARROW modeling possible with MODIS?***

Key Points



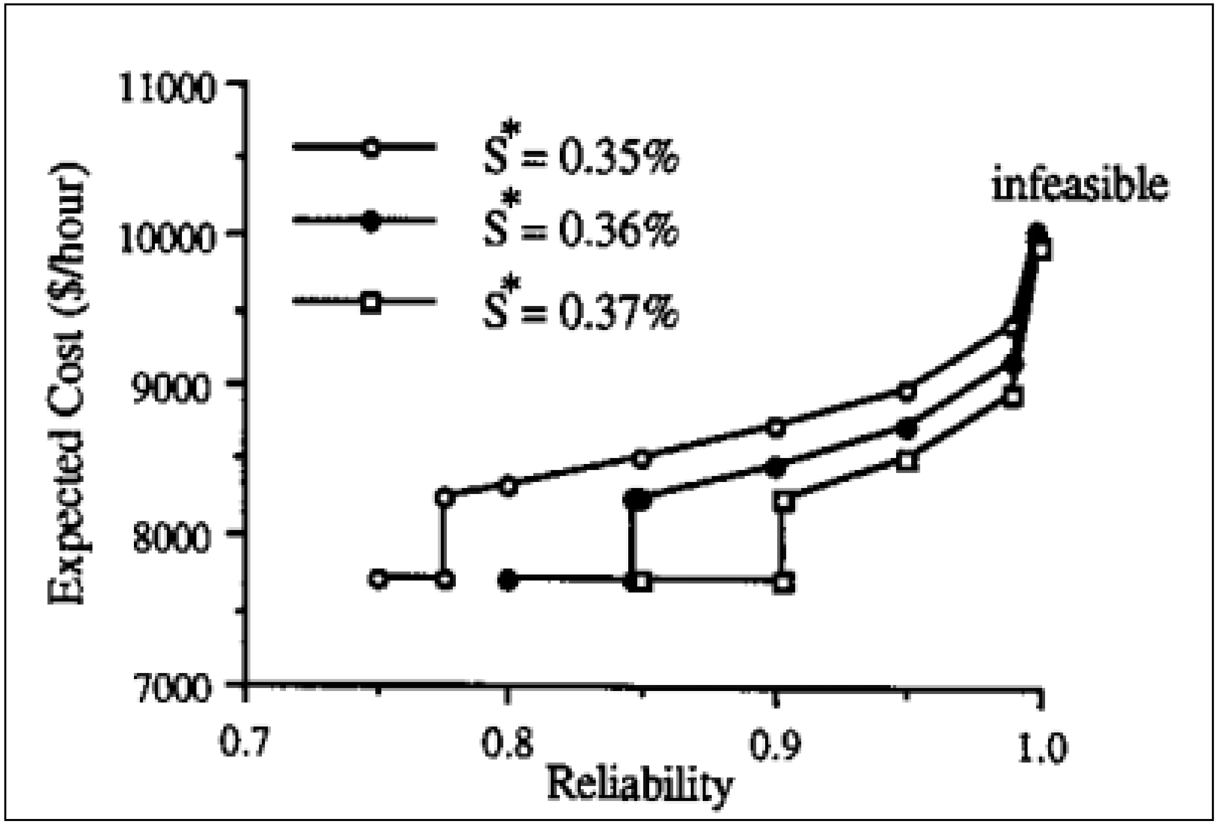
- **Project overview and measuring impact**
- **Model development**
  - SPARROW and dynamic SPARROW
  - Role of MODIS data
  - Potomac (Ches. Bay) application
- **New project applications**
  - Long Island Sound – nitrogen transport
  - Mississippi Basin – nutrients delivered to Gulf of Mexico
  - South Carolina public water supply reservoirs - cyanobacteria
- **Concluding comments**

Partners and User Community

- USGS
- USEPA
  - Chesapeake Bay Program
  - Narragansett Laboratory
  - Gulf of Mexico Program
- New England Interstate Water Pollution Control Commission (NEIWPCC)
- State of Connecticut
- State of South Carolina

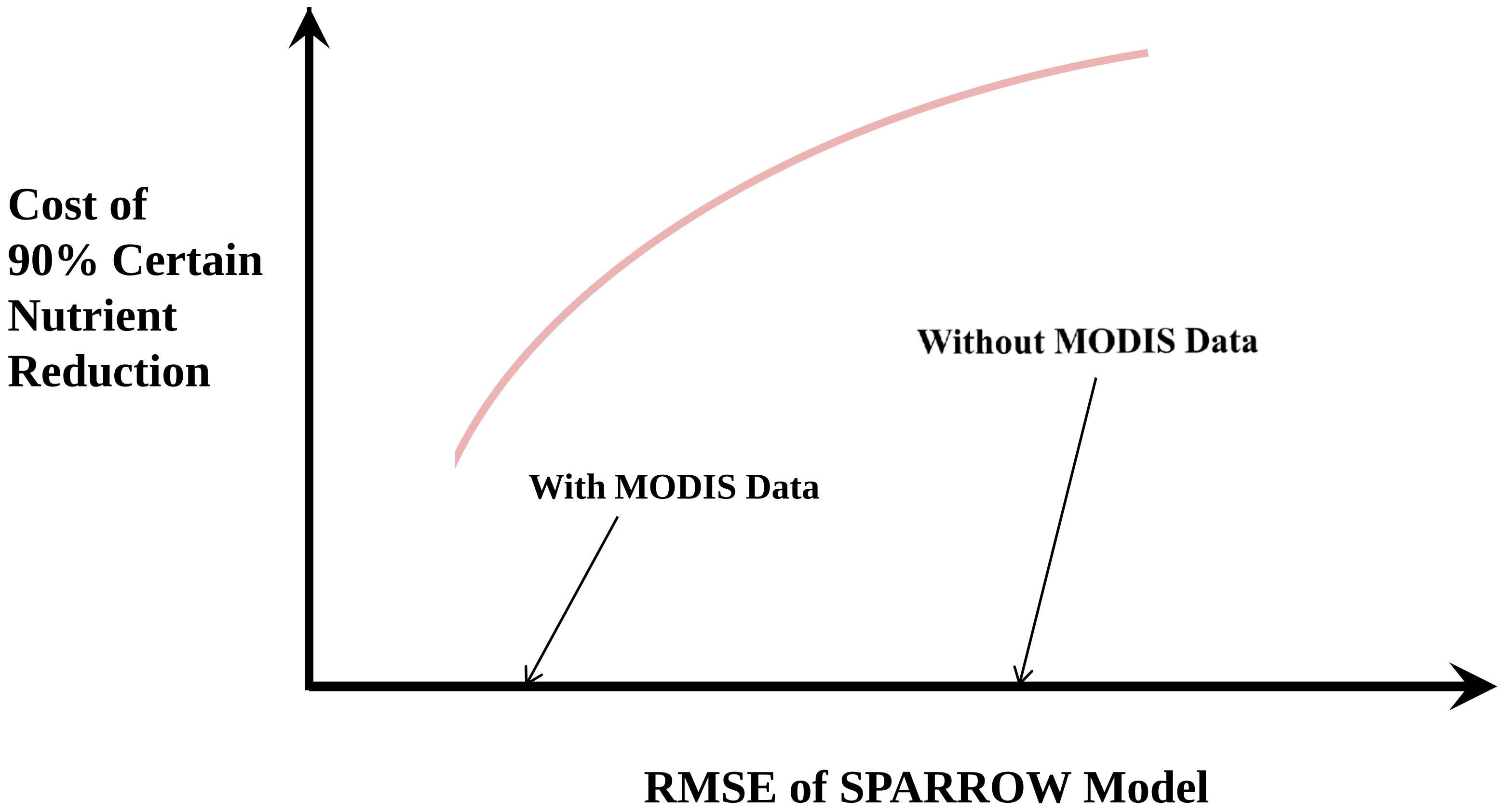
Cost vs Reliability

Ultimately, among our end goals: we will apply economic Value of Information methods to estimate the cost-effectiveness of MODIS-enhanced water management



Example Diagram

Cost of Nutrient Control vs Model Error



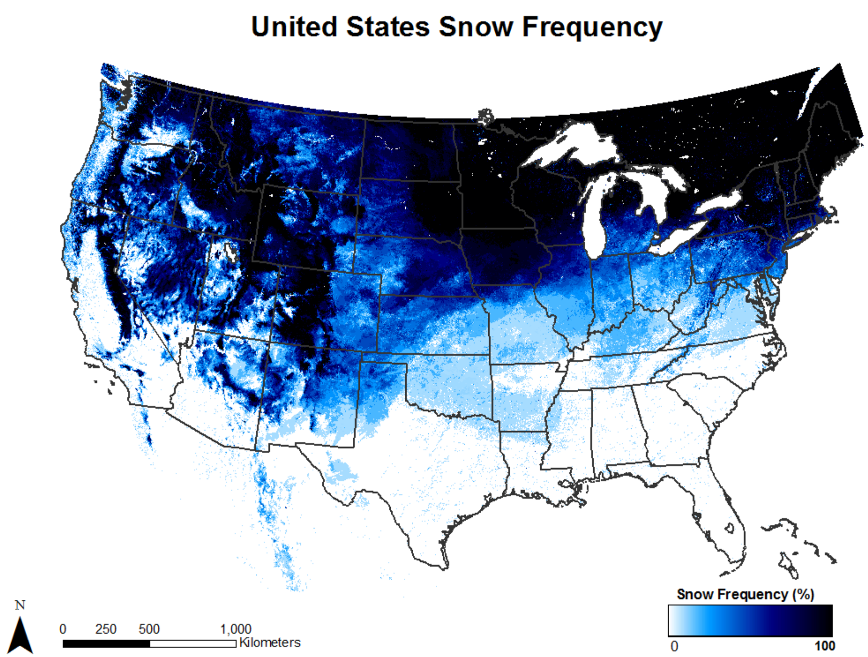
SPARROW Water Quality Model:

(**SPA**tially **R**eferenced **R**egression **o**n **W**atershed **A**ttributes)

- ***Mechanistic Features***
  - contaminant sources and landscape attributes linked to stream/river network
  - nonlinear contaminant processes
  - non-conservative transport
  - Steady-state mass balance form
  - dynamic version (with MODIS input) under development*

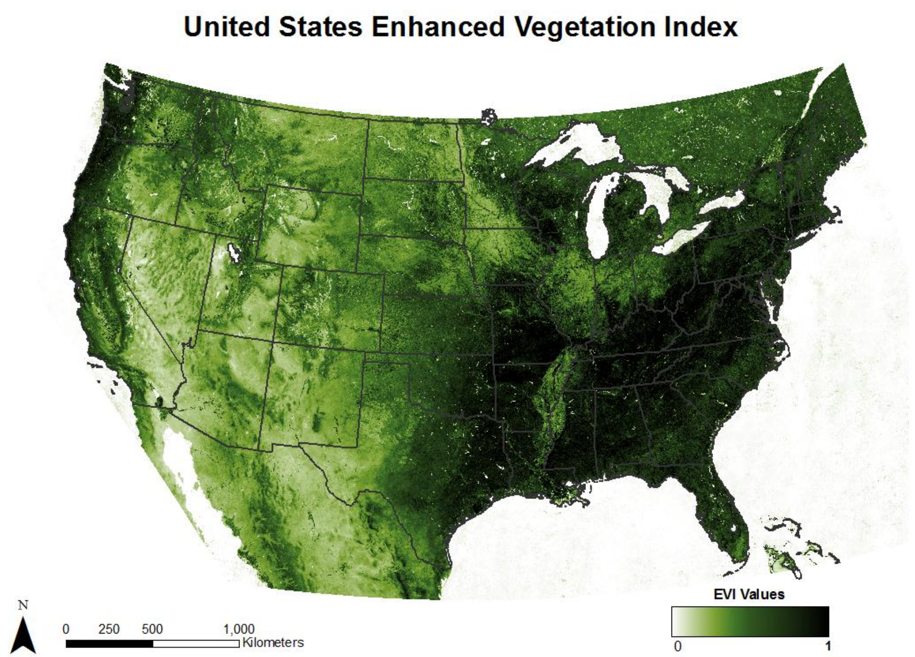
- ***Statistical Features***
  - "data-driven" (from large, long-term, monitoring network (1000+ sites)
  - statistical calibration (nonlinear regression)
  - coefficients estimated from the data, not litt.
  - promotes hypothesis testing of mechanistic interpretation
  - provides error quantification

New seasonal data sets derived from MODIS 8-day 500-m surface reflectance (WY 2001-2009)



Seasonal snow cover frequency

$$\boxed{\text{snow freq} = N_{snow}/N_{observations}}$$



Median Enhanced Vegetation Index (EVI)

$$\boxed{EVI = G\frac{r_{NIR} - r_{red}}{r_{NIR} + (C_1 r_{red} - C_2 r_{blue}) + L}}$$

Also: Gross Primary Productivity and Land Surface Water Index

Preliminary Calibration of Dynamic SPARROW Model of Total Nitrogen in Potomac Basin

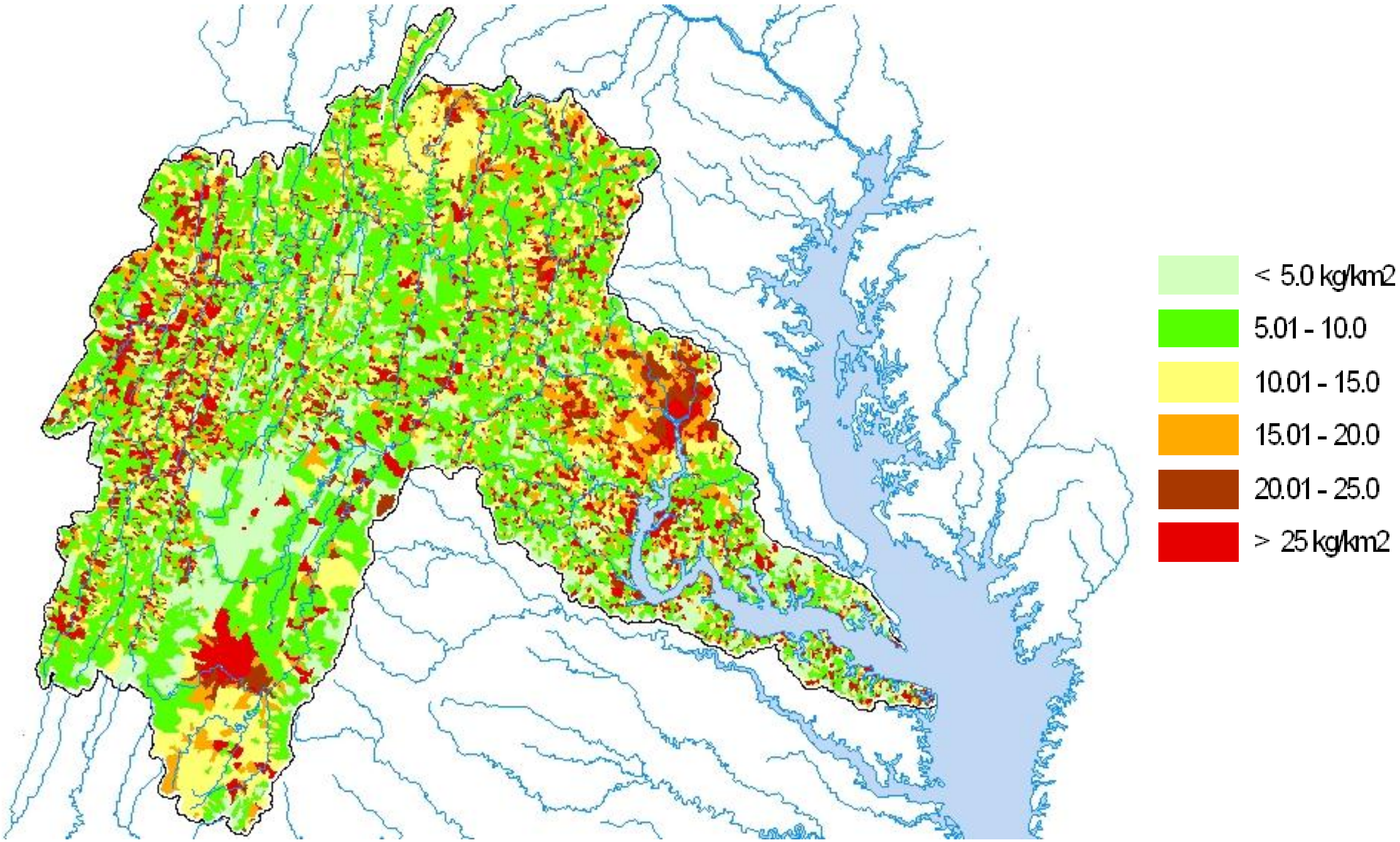
- Based on NHD stream network ($16{,}000^{+}$ reaches/catchments)
- 81 water-quality monitoring stations for “observed” flux
- TN sources: point, urban runoff, atmosphere, fertilizer, farm animal waste, catchment “storage”
- Land-to-water drivers: runoff, delta runoff, MODIS vegetation index
- Seasonal time series of all data for fall 2001 through fall 2008

Calibration Results

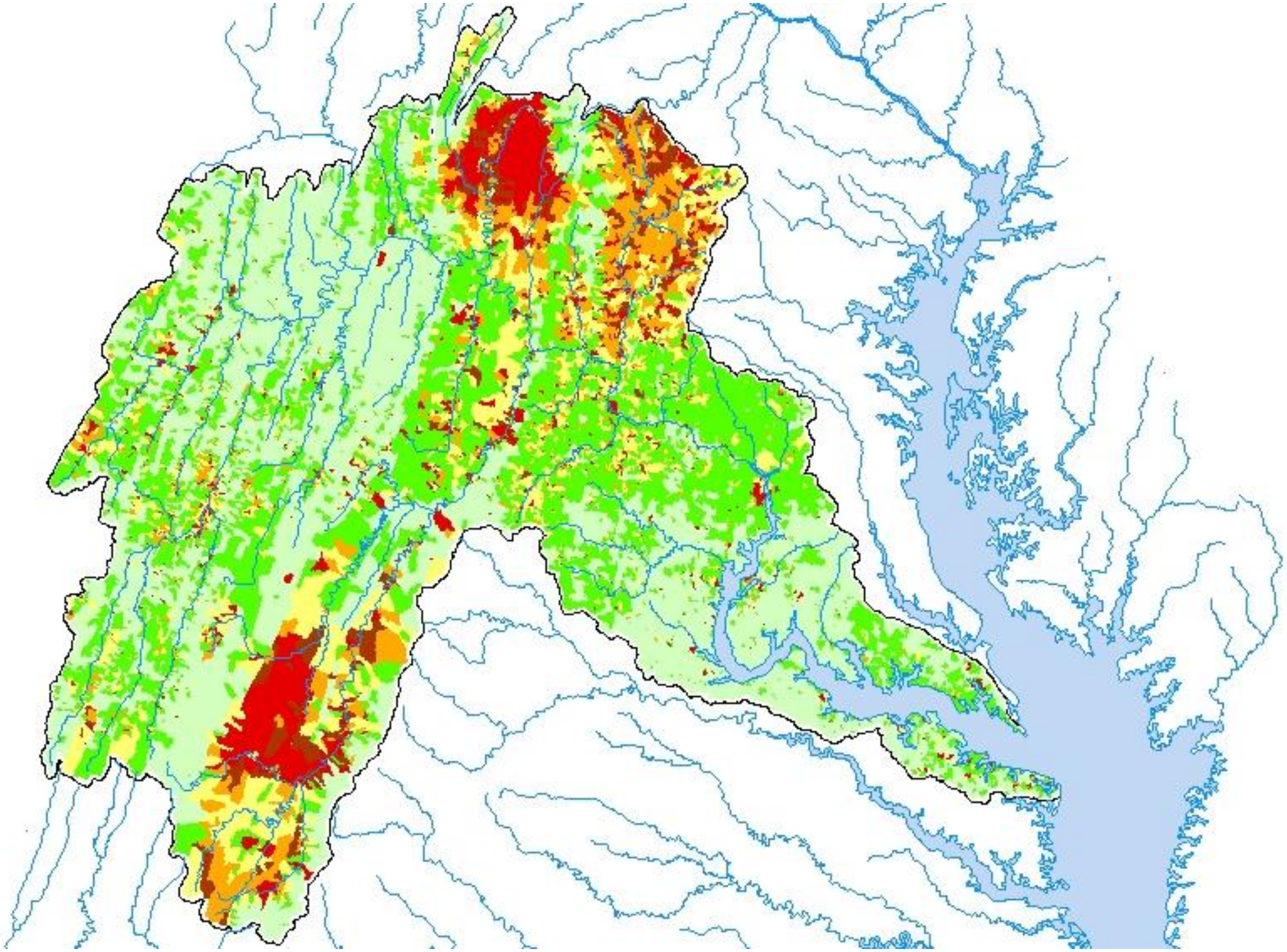
No. of observations	2268
R^2	0.90
Yield R^2	0.68
RMSE	0.69

N Source	Units	Coeff.	Significance (p)
Point sources	kg/yr	0.66	$< 10^{-4}$
Urban	sq km	427	$< 10^{-4}$
Atmos.	kg/yr	0.11	$< 10^{-4}$
Fertilizer	kg/yr	0.034	$< 10^{-4}$
Animal waste	kg/yr	0.060	$< 10^{-4}$
“Storage	kg/yr	0.35	$< 10^{-4}$
ln EVI	-	-0.90	$< 10^{-4}$

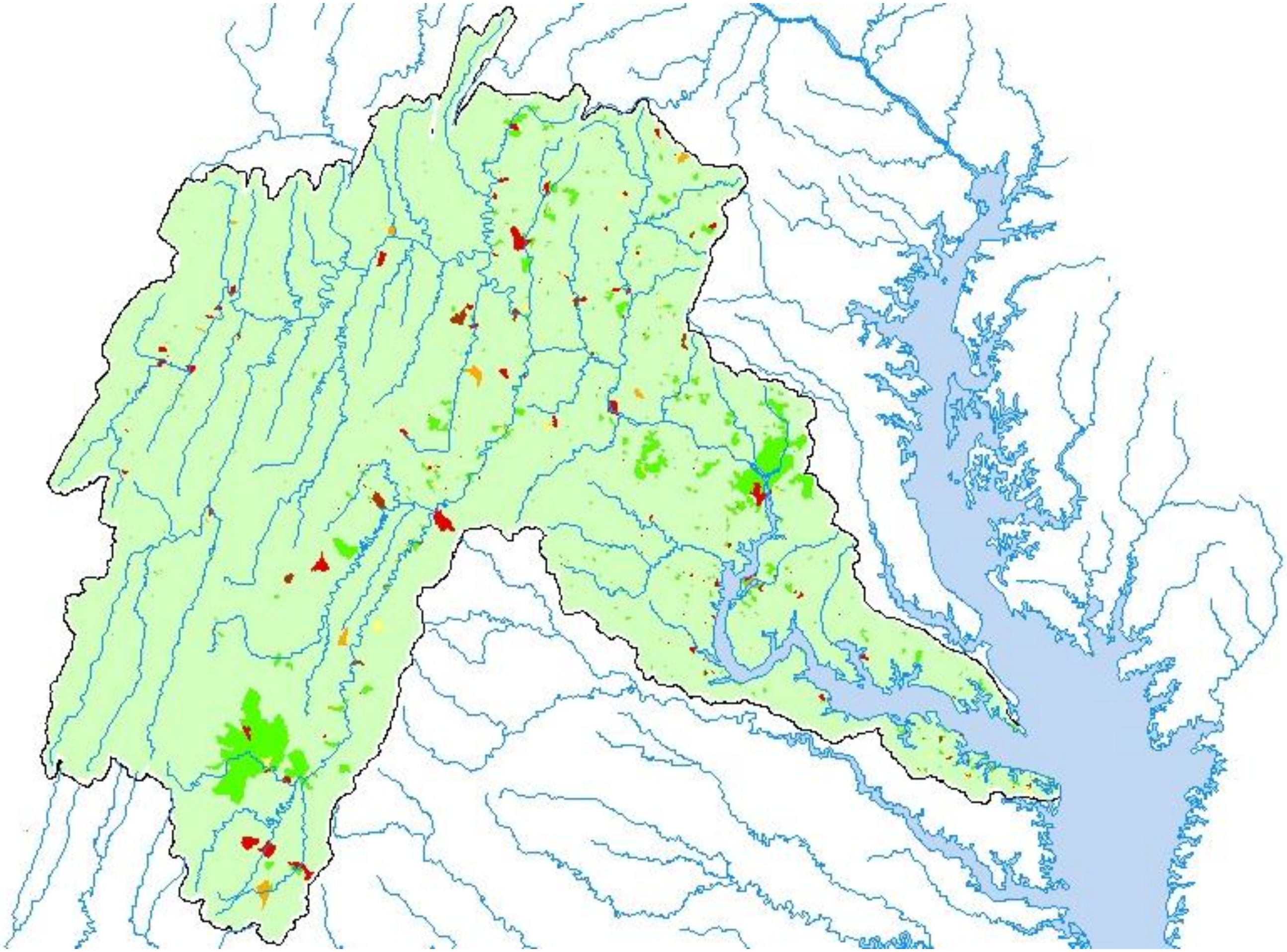
Total Nitrogen Yield (kg km^{-1} day^{-1})
Winter (J, F, M) 2006



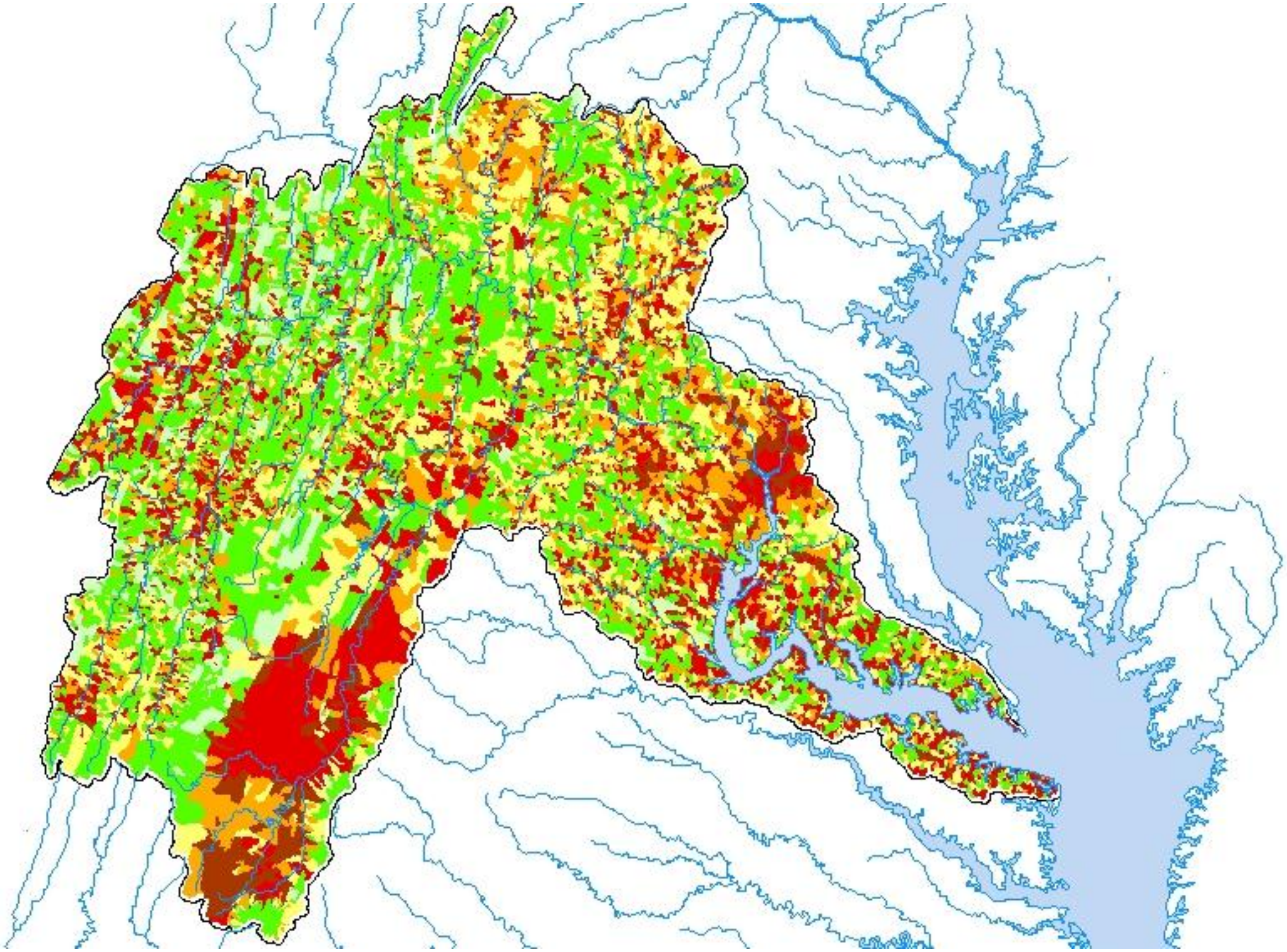
Total Nitrogen Yield (kg km^{-1} day^{-1})
Spring 2006



Total Nitrogen Yield (kg km^{-1} day^{-1})
Summer 2006



Total Nitrogen Yield (kg km^{-1} day^{-1})
Fall 2006

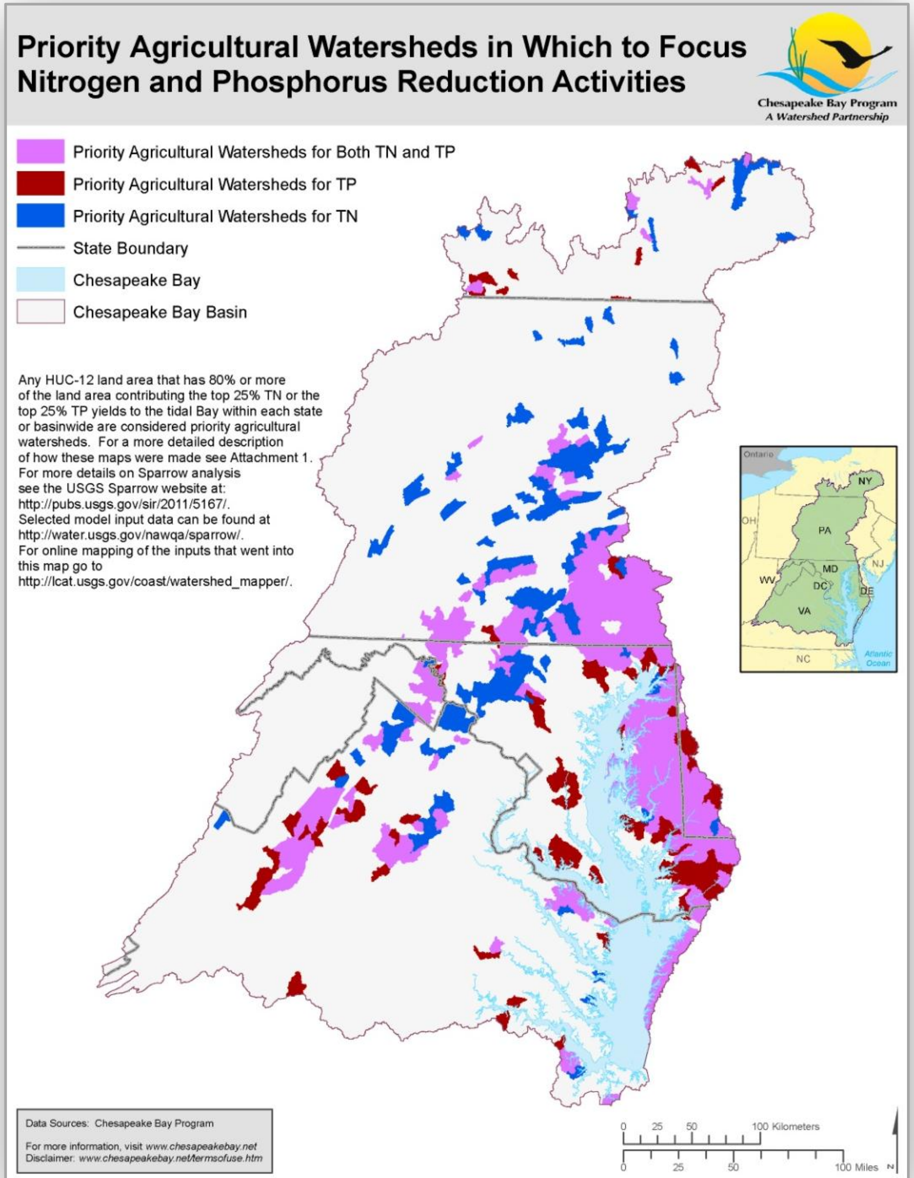


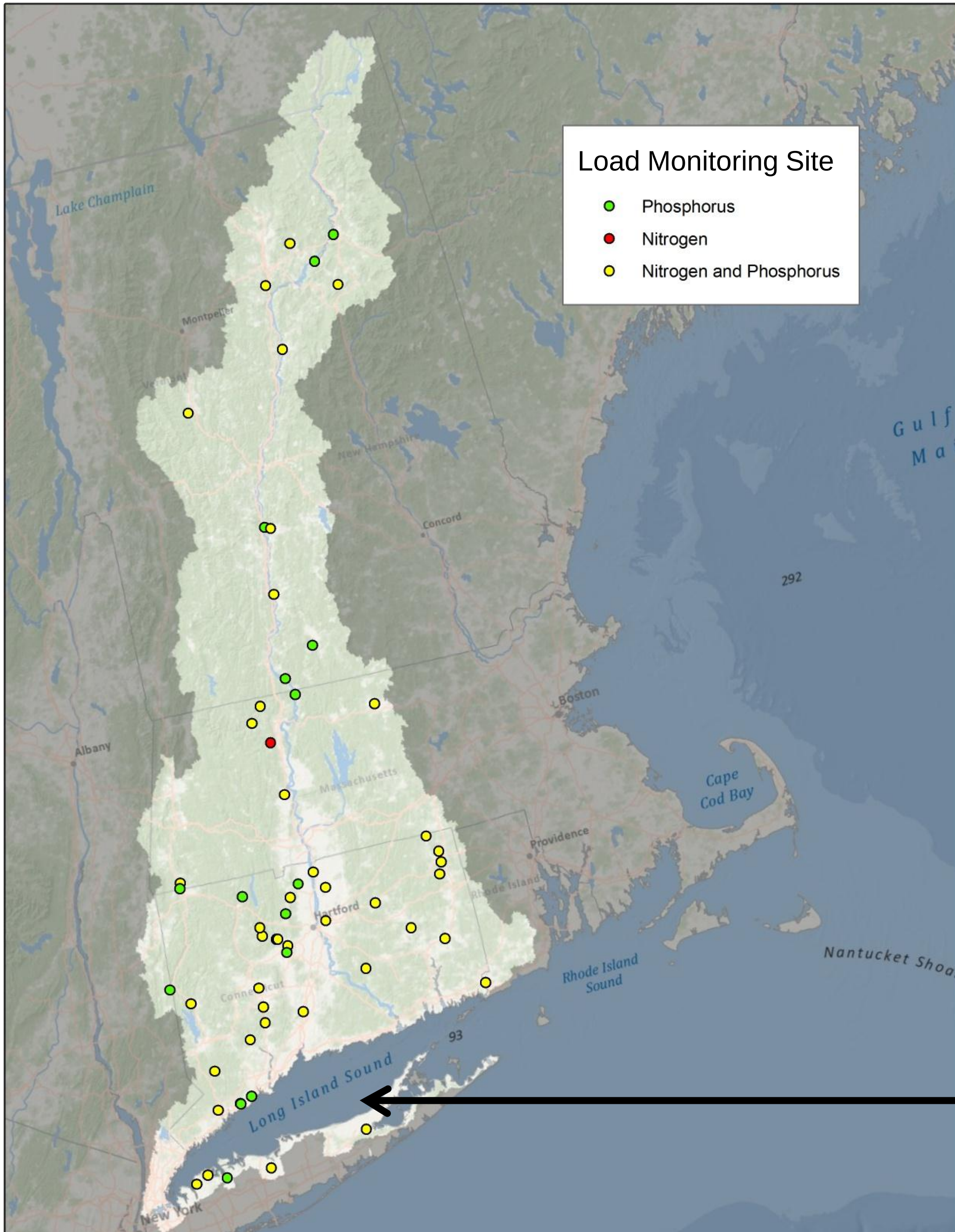
Conclusions

- The results of an initial attempt to calibrate a dynamic SPARROW model of reactive nitrogen based on seasonal time series of water quality and basin attribute data were highly encouraging.
- EVI was an especially strong predictor, appearing to account for seasonal retention of nitrogen in basin vegetation.
- Model predictions for the entire 16,000-reach stream network show moderately accurate (and seemingly realistic) seasonal and year-to-year variations in yield. Model coefficient estimates were very precise due to many observations.
- Long-term simulation of average Potomac Basin nitrogen yield under the influence of runoff and temperature change suggests that changes in basin storage may play an important role in climate effects on water quality.

SPARROW Model Applications

Targeting of Management Actions in Chesapeake Bay Watershed



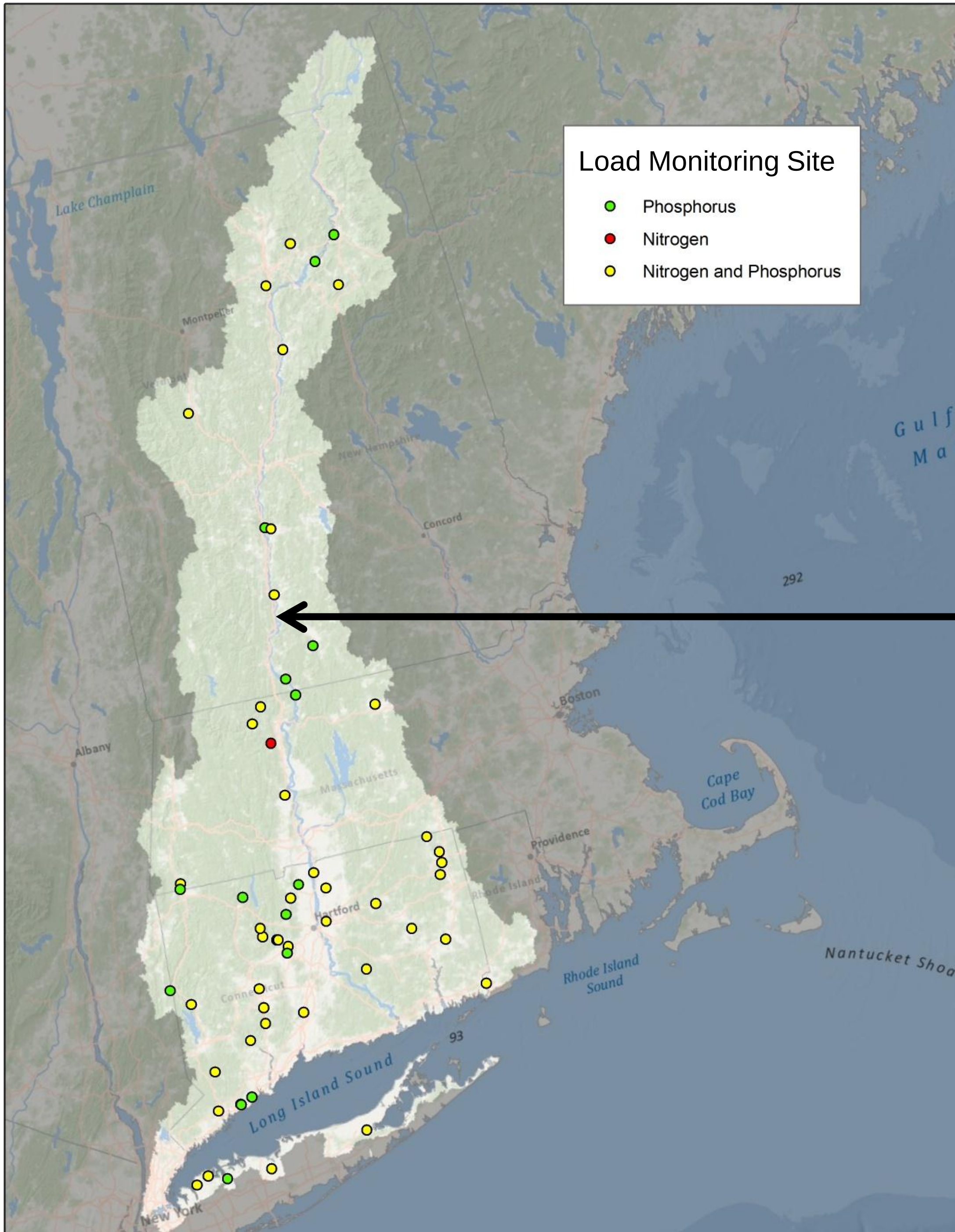


Application to Long Island Sound (LIS)

Low concentrations of dissolved oxygen (hypoxia), as a result of nitrogen enrichment, often occur during the summer in the western part of LIS.

Partners / User Community

- New England Interstate Water Pollution Control Commission (NEIWPCC)
- Four New England States especially Connecticut Dept. Env. Protection
- New York Dept. Env. Conservation
- U.S. Environmental Protection Agency (USEPA)



Long Island Sound (LIS)

Nitrogen transport from the watershed to LIS varies seasonally. Much of the nitrogen transport occurs during the spring freshet.

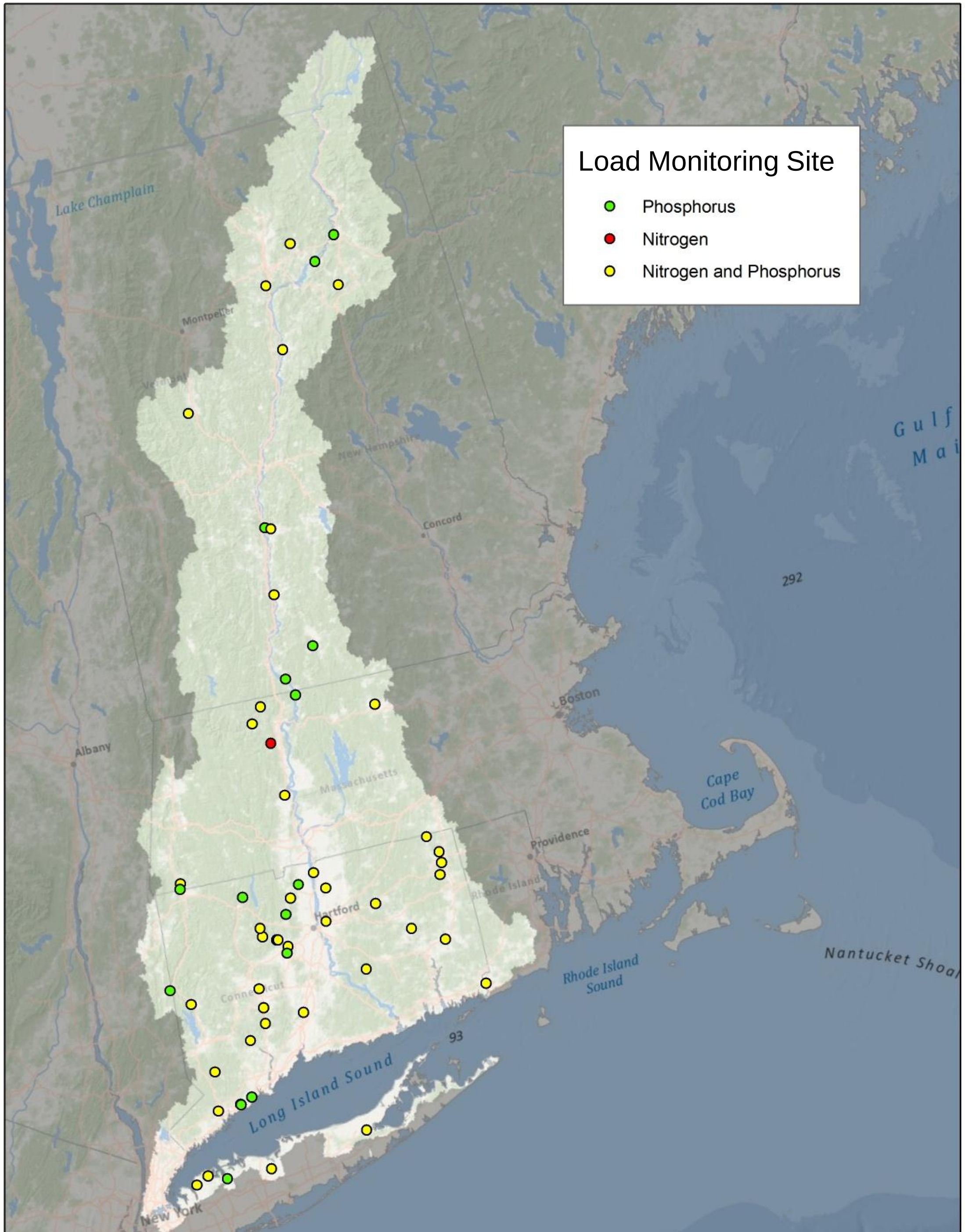
Modeling Approach

Dynamic – Seasonal SPARROW
Winter 2001 - Summer 2009

Seasonal loads at monitoring sites are the dependent variable

Standard suite of SPARROW predictors plus NASA predictors compiled seasonally:

- The Enhanced Vegetation Index (EVI)
- Percent snow cover



Long Island Sound (LIS)

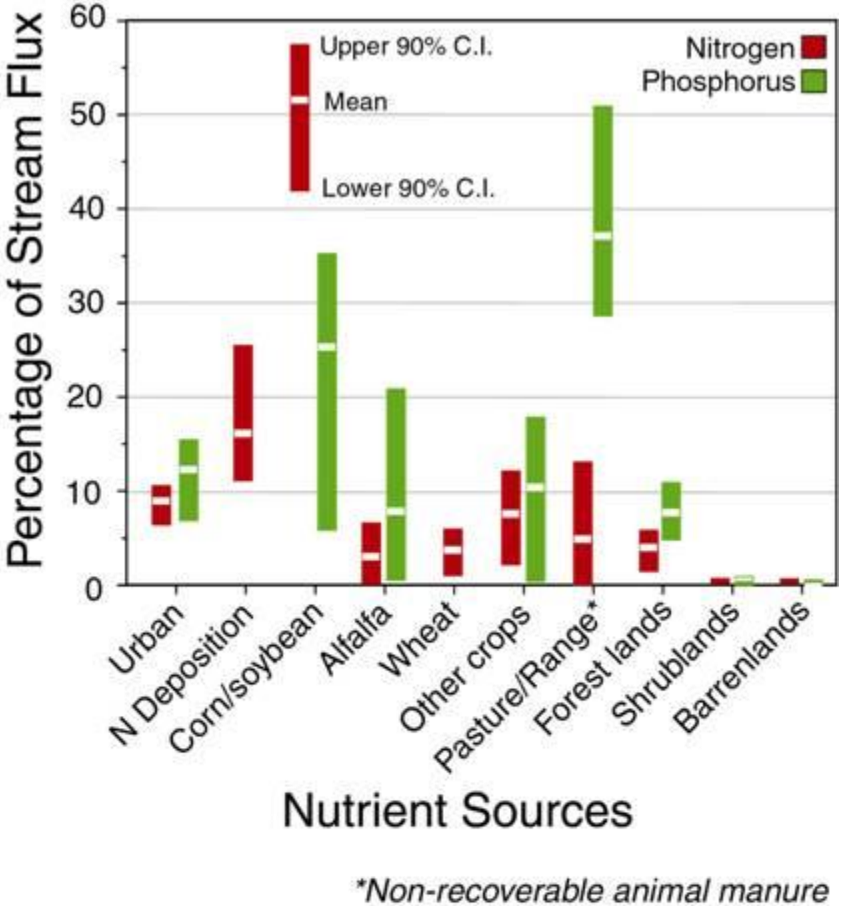
Anticipated outcome

Improved understanding of the source and transport of nitrogen to LIS and how it varies seasonally.

Intended to aid in targeting nutrient controls.

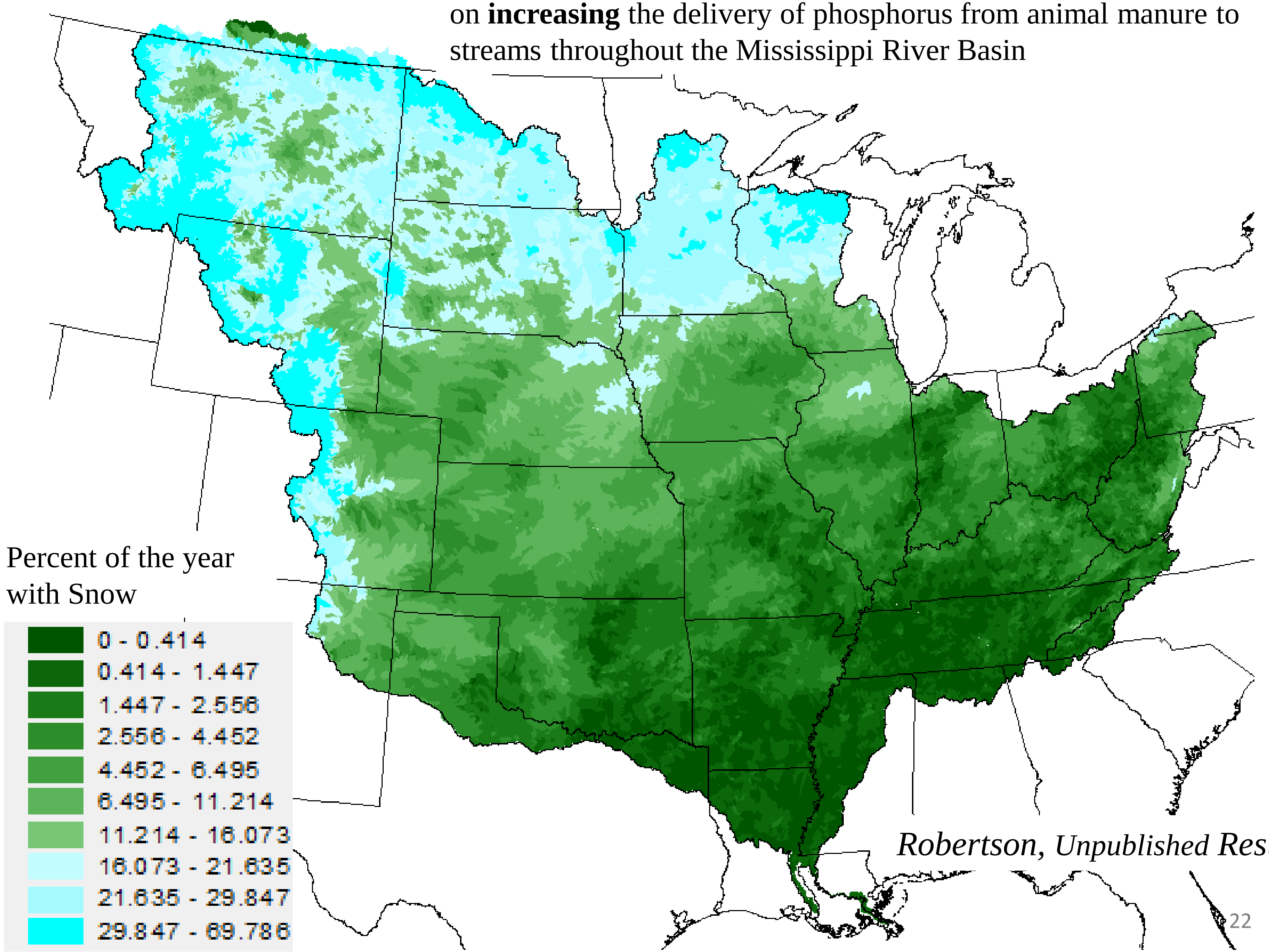
Quantifying the Sources of Nutrients Delivered to the Gulf of Mexico

Mississippi/Atchafalaya River Basin



Alexander et al., 2008, Environ. Sci. Technol., v 42

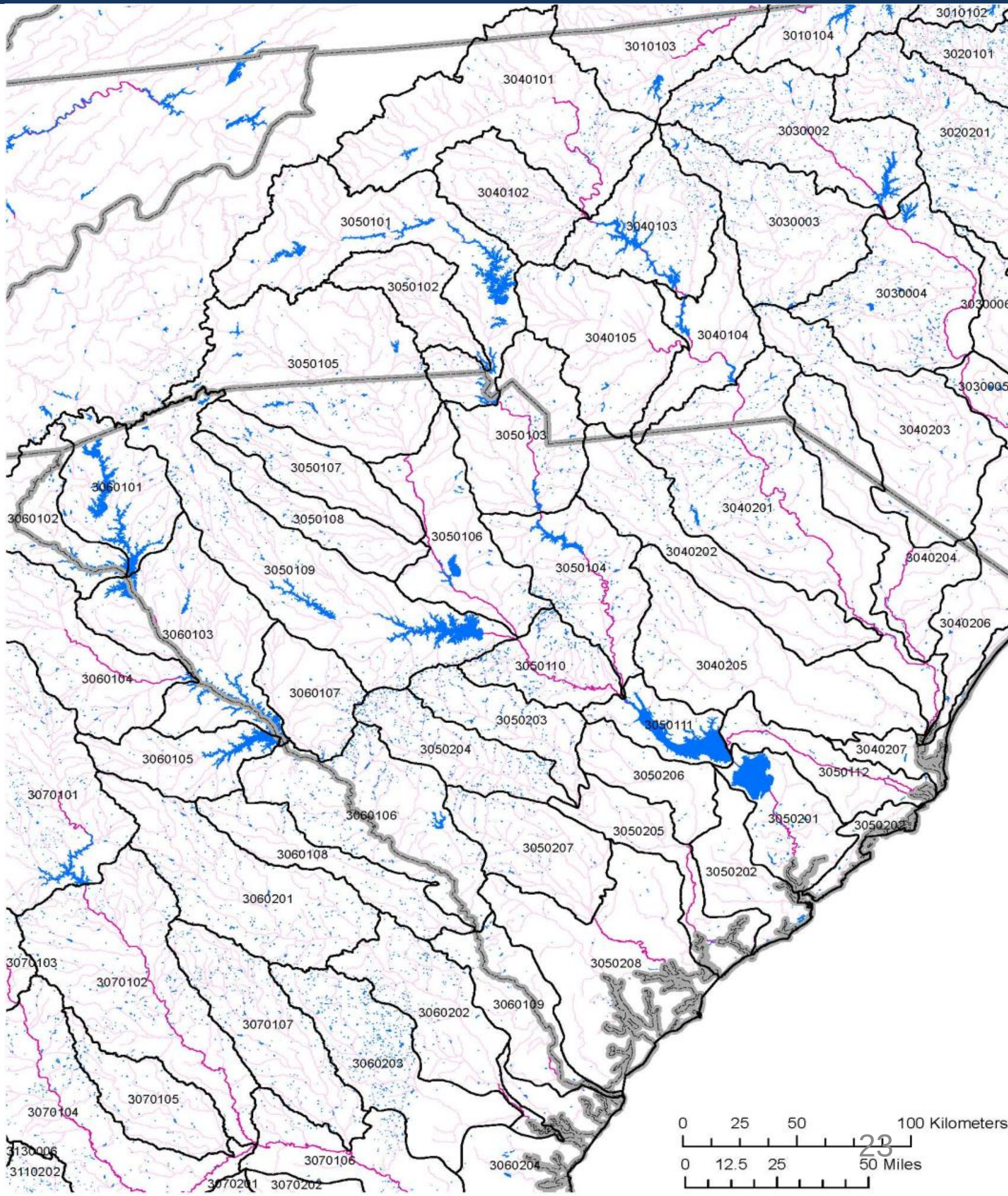
Percent of the year with frozen ground (snow) has a significant effect on **increasing** the delivery of phosphorus from animal manure to streams throughout the Mississippi River Basin



Robertson, Unpublished Results

Predicting Cyanobacteria Blooms in South Carolina Drinking Water Reservoirs

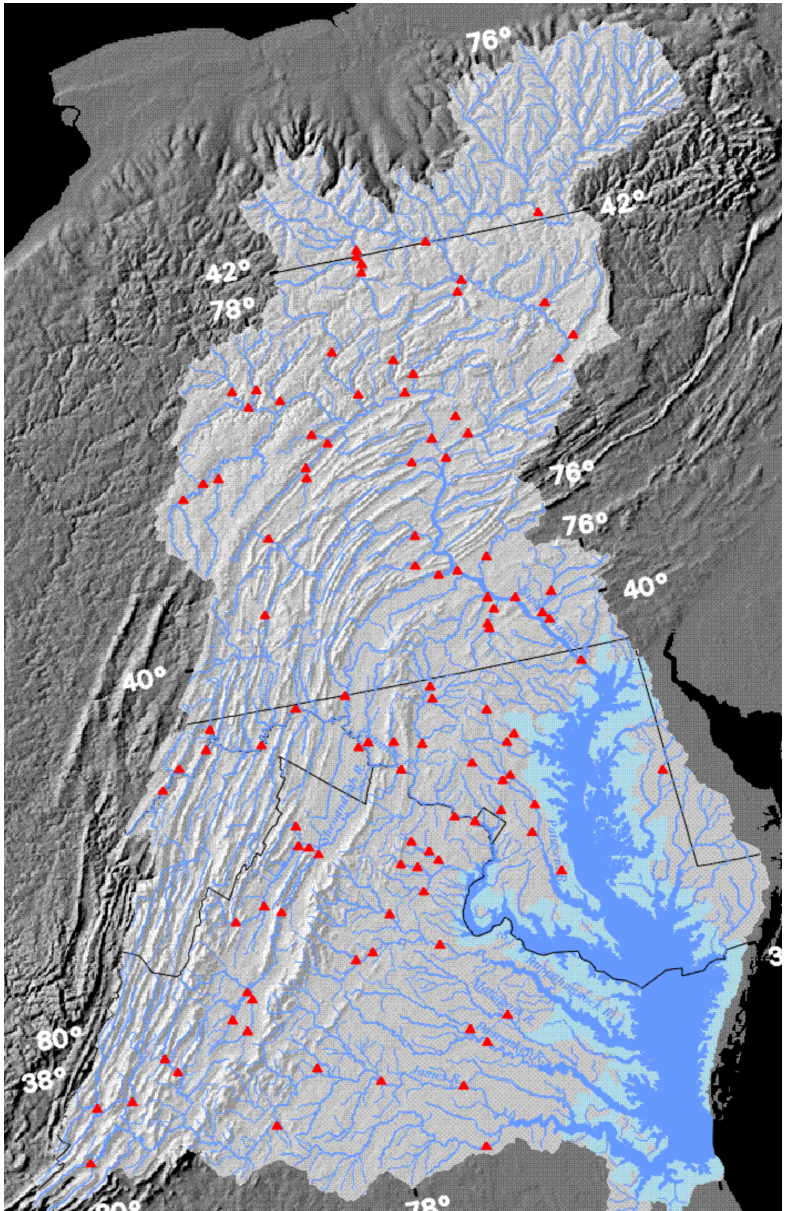
- Cyanobacteria cause taste/odor and toxicity problems; linked to high N:P ratios
- Existing SPARROW models are used to predict mean annual N:P conditions
- State officials would prefer seasonally- specific (spring/summer) predictions
- Seasonal SPARROW TN and TP models with MODIS inputs under development



Back Up Slides

Importance of Large Numbers of WQ Sites

Chesapeake Bay Example



SPARROW's Reach-Scale Mass Balance

Reach network relates watershed data to monitored loads

$$LOAD_i = \left\{ \sum_{j\in J(i)} \left[\sum_{n=1}^{N} S_{n,j}\beta_n \exp(-\alpha' Z_j) \right] \prod_m \exp(-\delta_m^s T_{i,j,m}) \prod_l 1/(1+\lambda^r q_{i,j,l}^{-1}) \right\} \exp(\varepsilon_i)$$

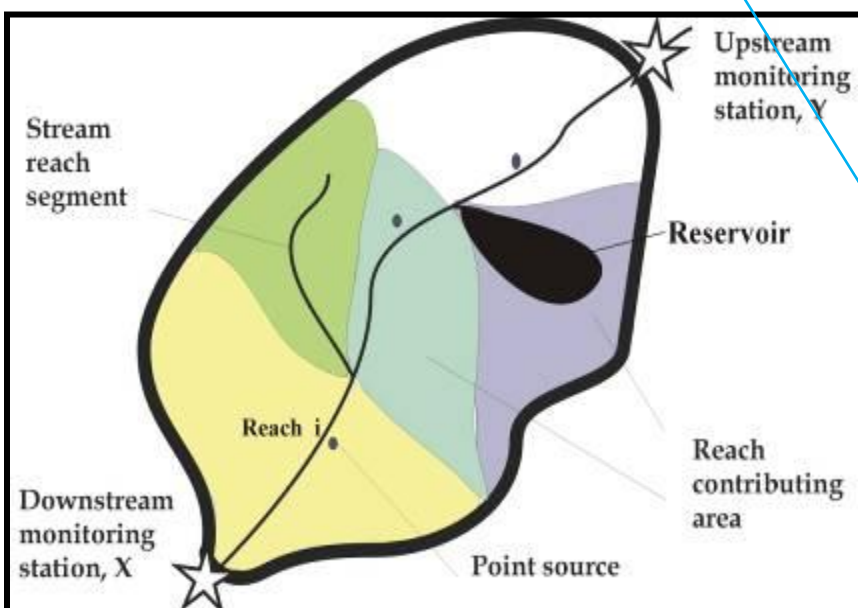
Monitored Stream Load

Sources

Land-to-water transport

Aquatic transport

Error

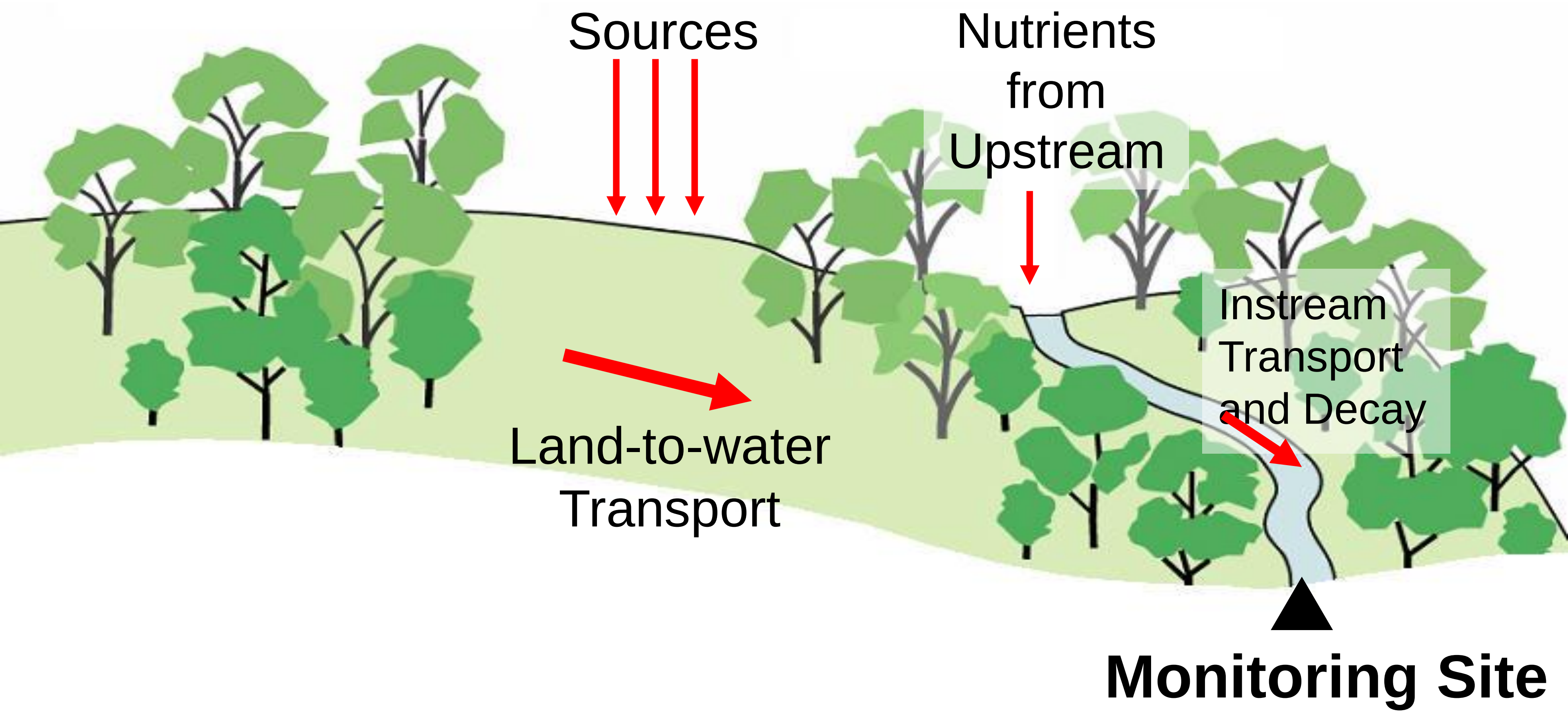


Required Modification of SPARROW Equation

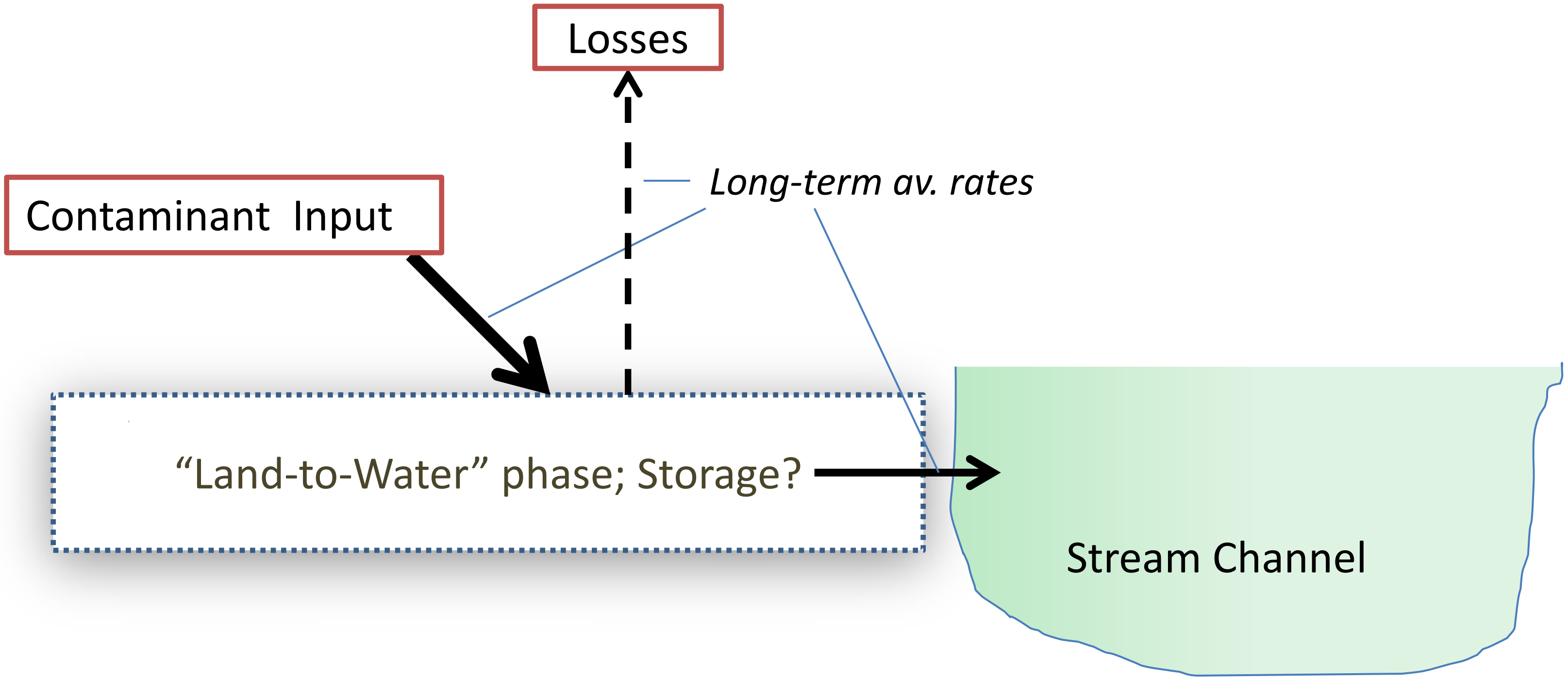
1. Addition of runoff, and lag-1 runoff, to Land-to-water transport term. *(MODIS data introduced here)*

2. Addition of lag-1 source term(s) based on observed downstream flux in previous time step.

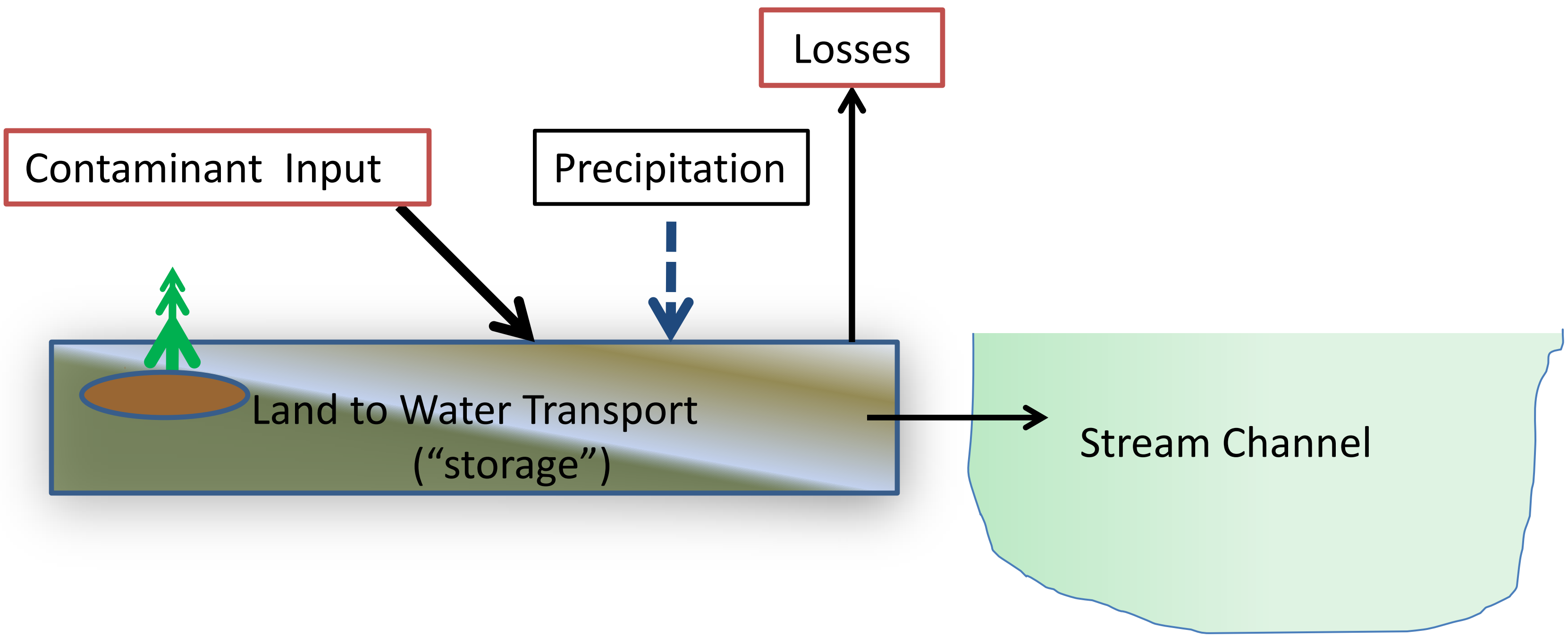
SPARROW Integrates Monitoring Data with Information on Watershed Characteristics and Nutrient Sources



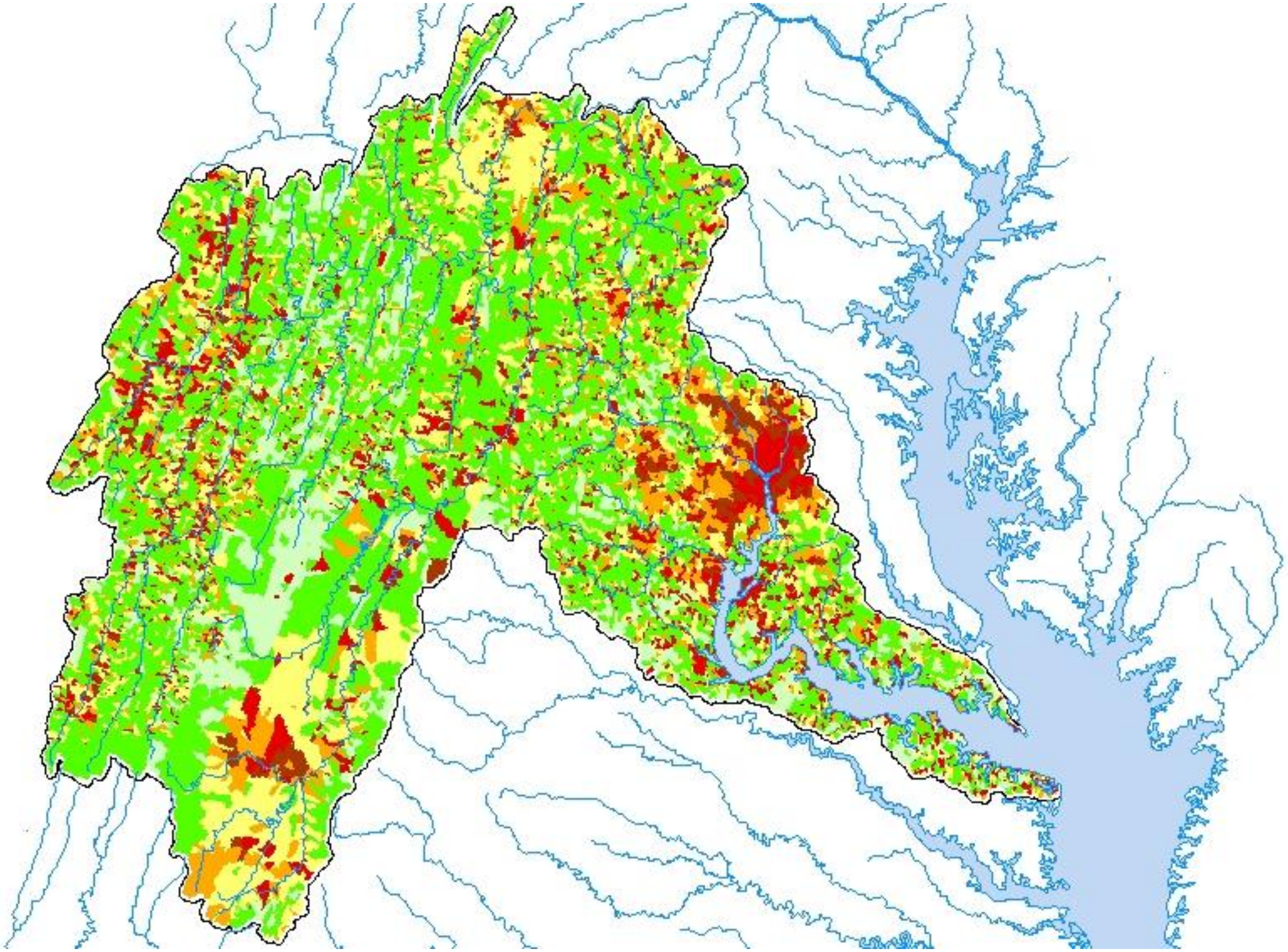
In a conventional (steady-state) SPARROW model, contaminant material from "sources" has an unknown mass and residence time in the "land-to-water" phase. In short, "storage" is unknown.



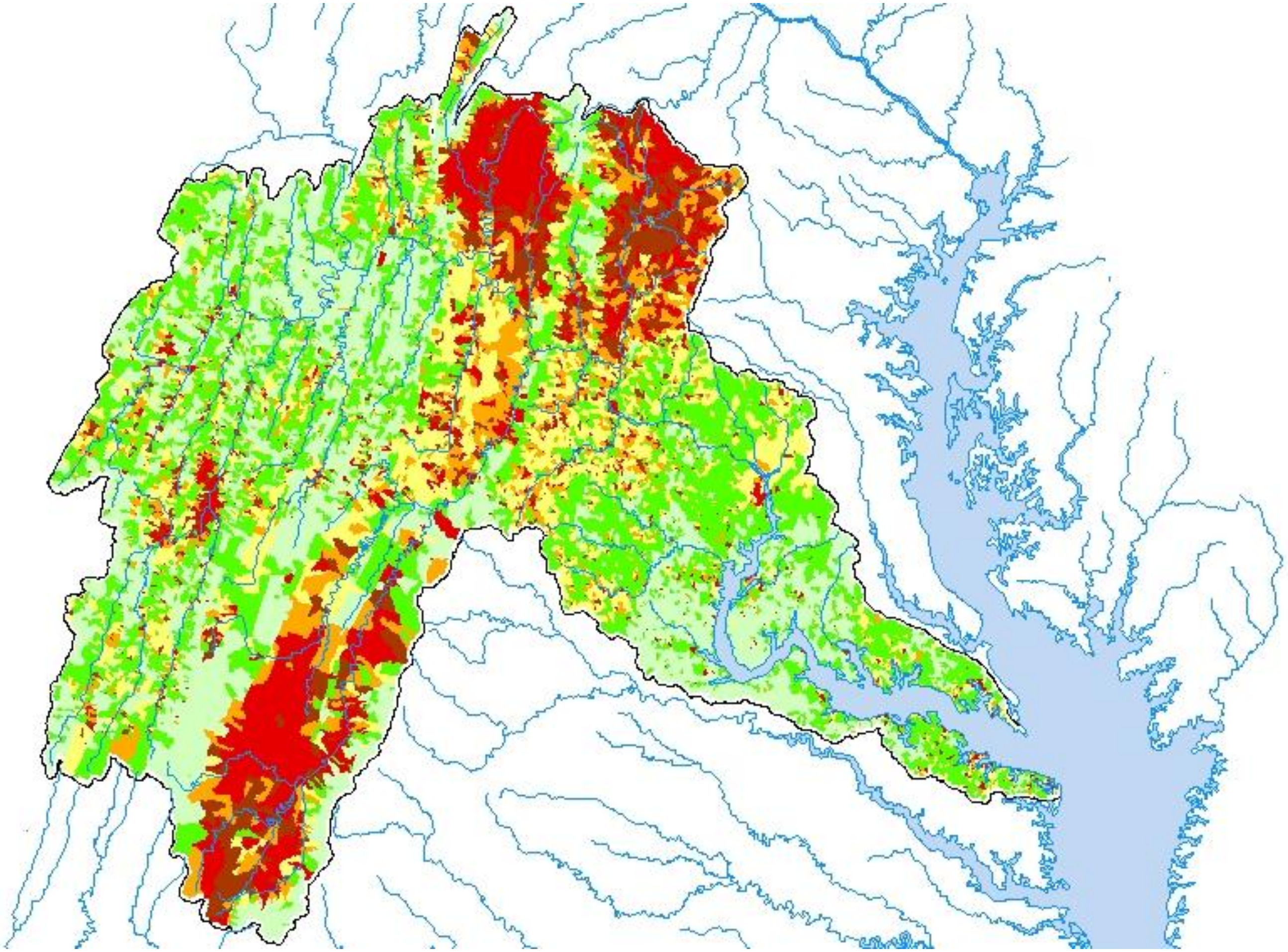
An essential mechanism of dynamic behavior in watersheds is temporary "storage". Storage may be either surface or subsurface . Export to stream is a function of amount in storage, hydrologic forcing, and residence time in storage.



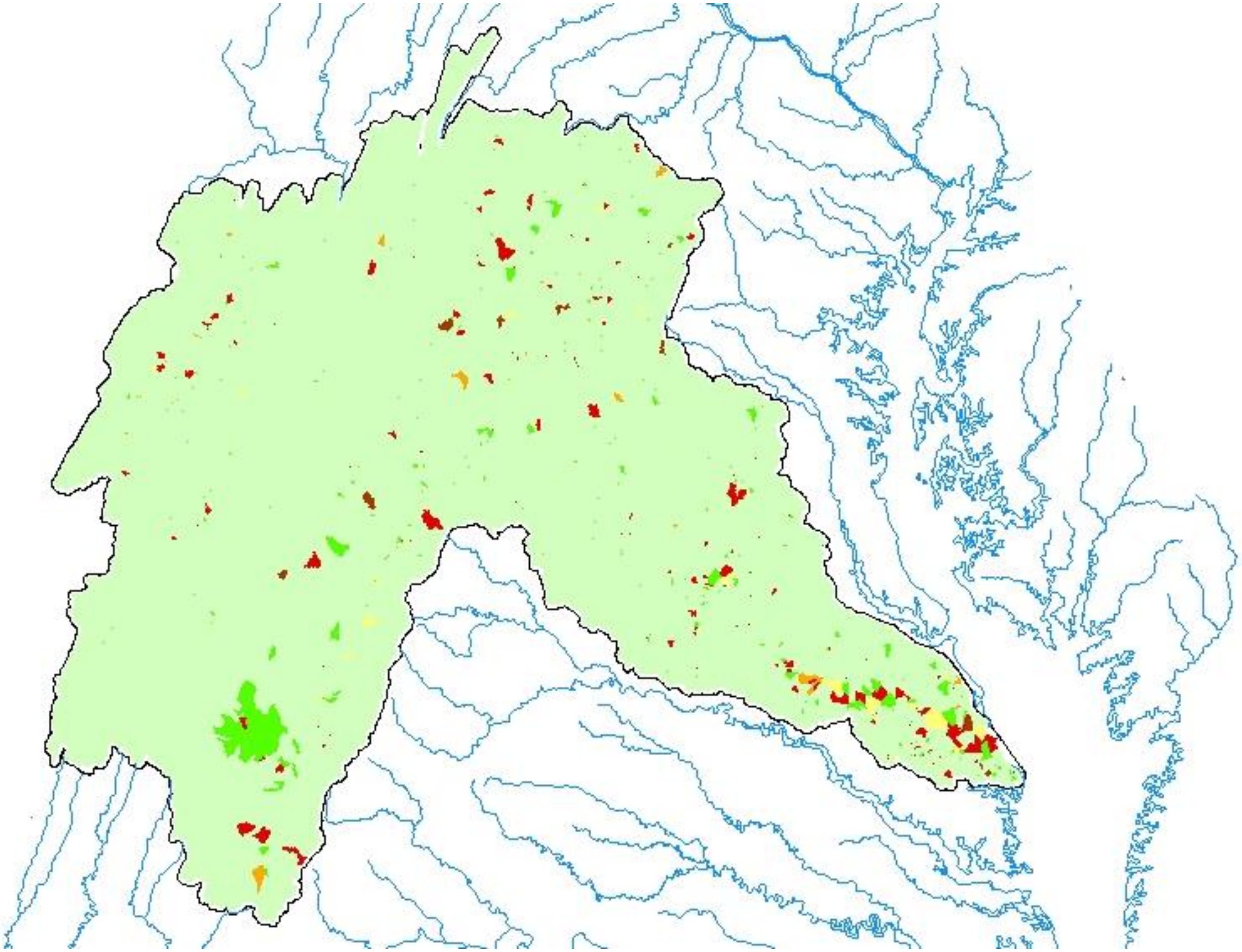
Total Nitrogen Yield (kg km^{-1} day^{-1})
Winter 2007



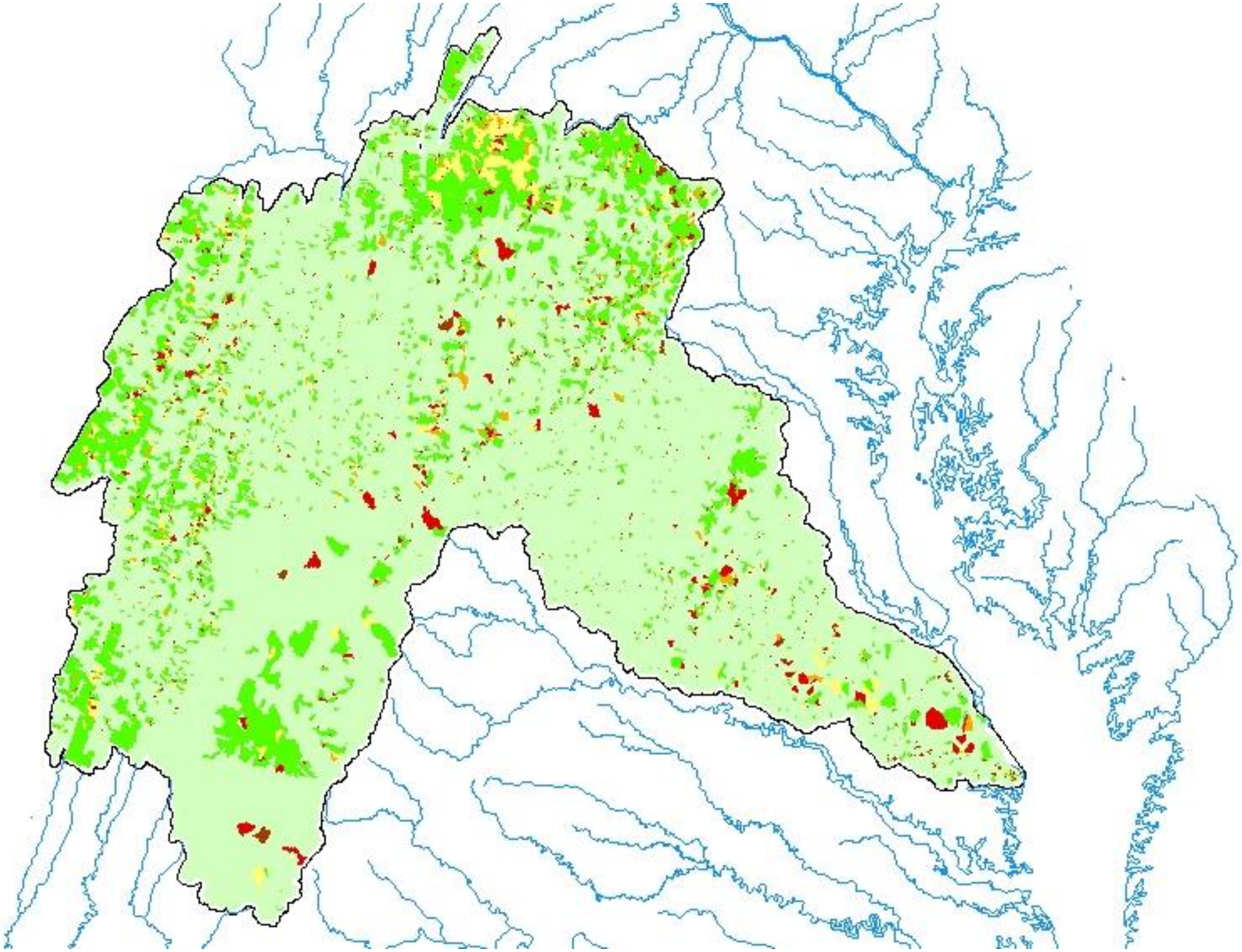
Total Nitrogen Yield (kg km^{-1} day^{-1})
Spring 2007



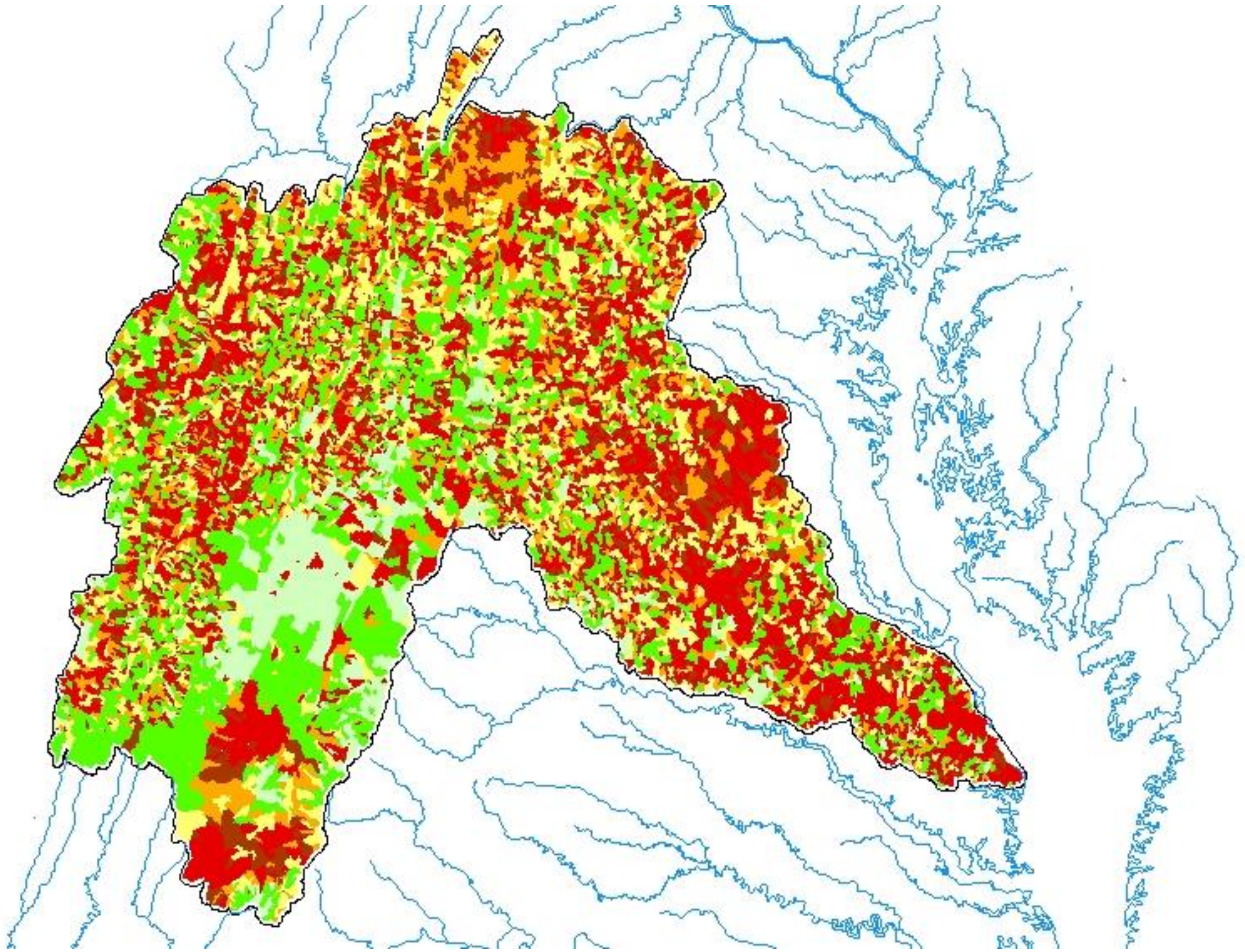
Total Nitrogen Yield (kg km^{-1} day^{-1})
Summer 2007



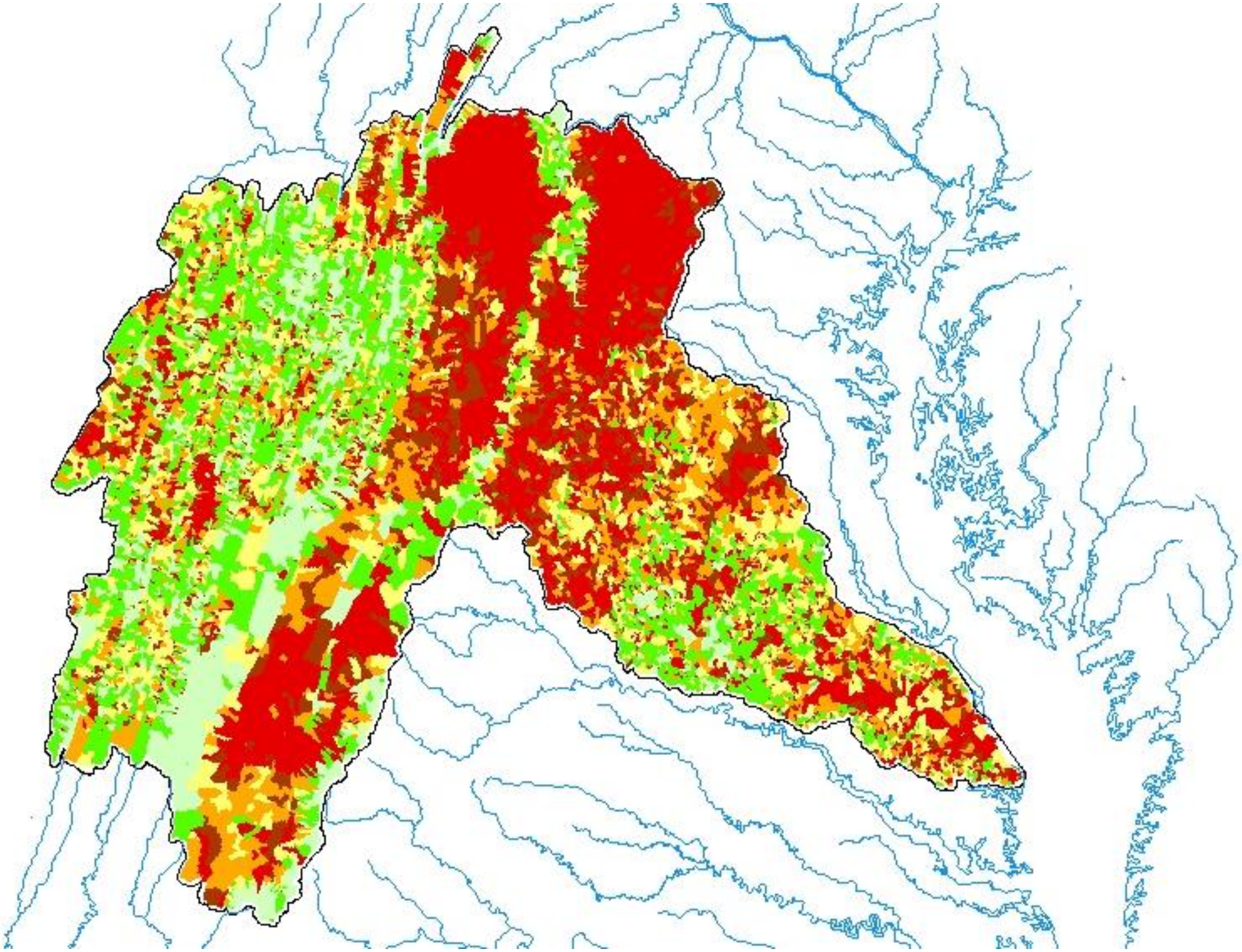
Total Nitrogen Yield (kg km^{-1} day^{-1})
Fall 2007



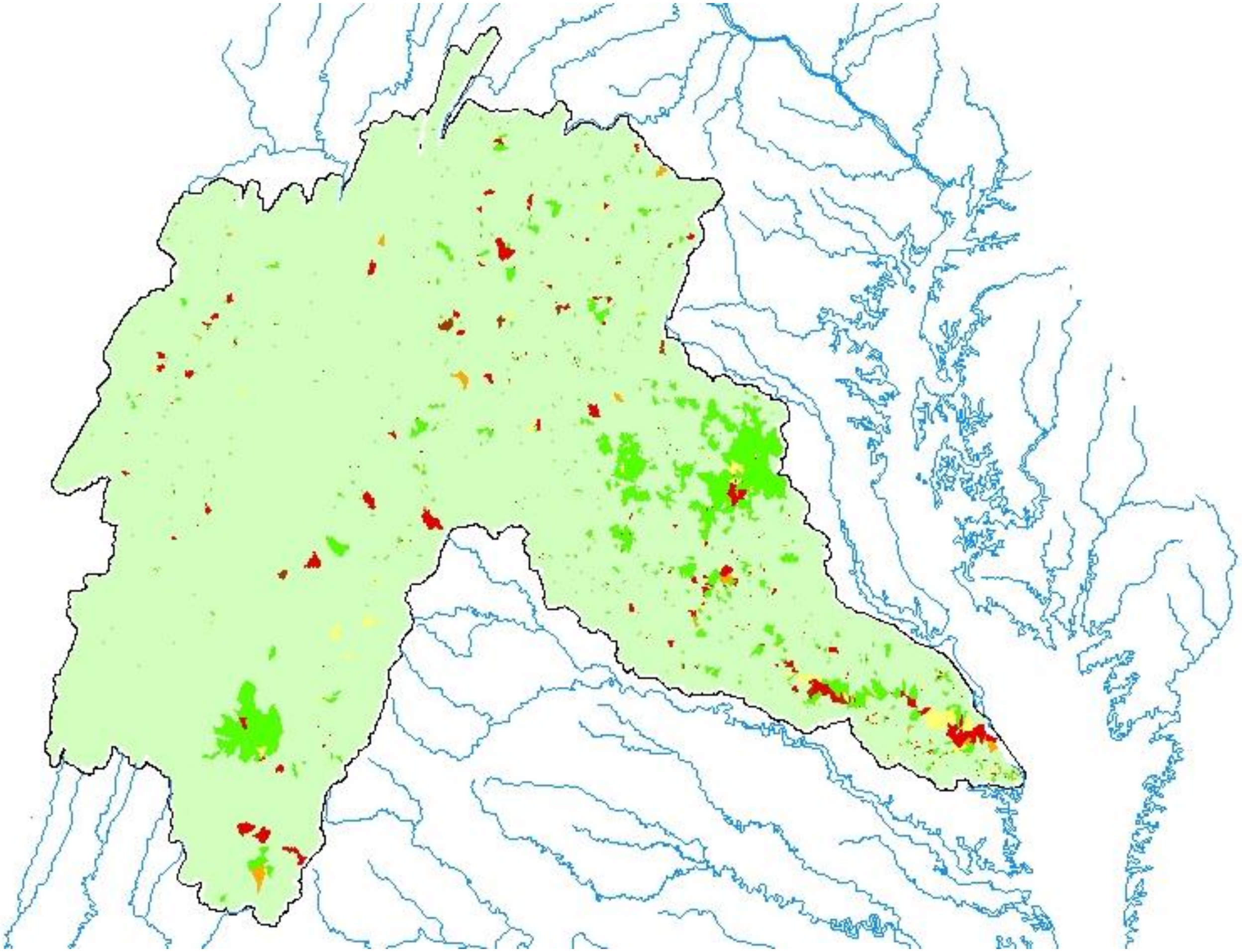
Total Nitrogen Yield (kg km^{-1} day^{-1})
Winter 2008



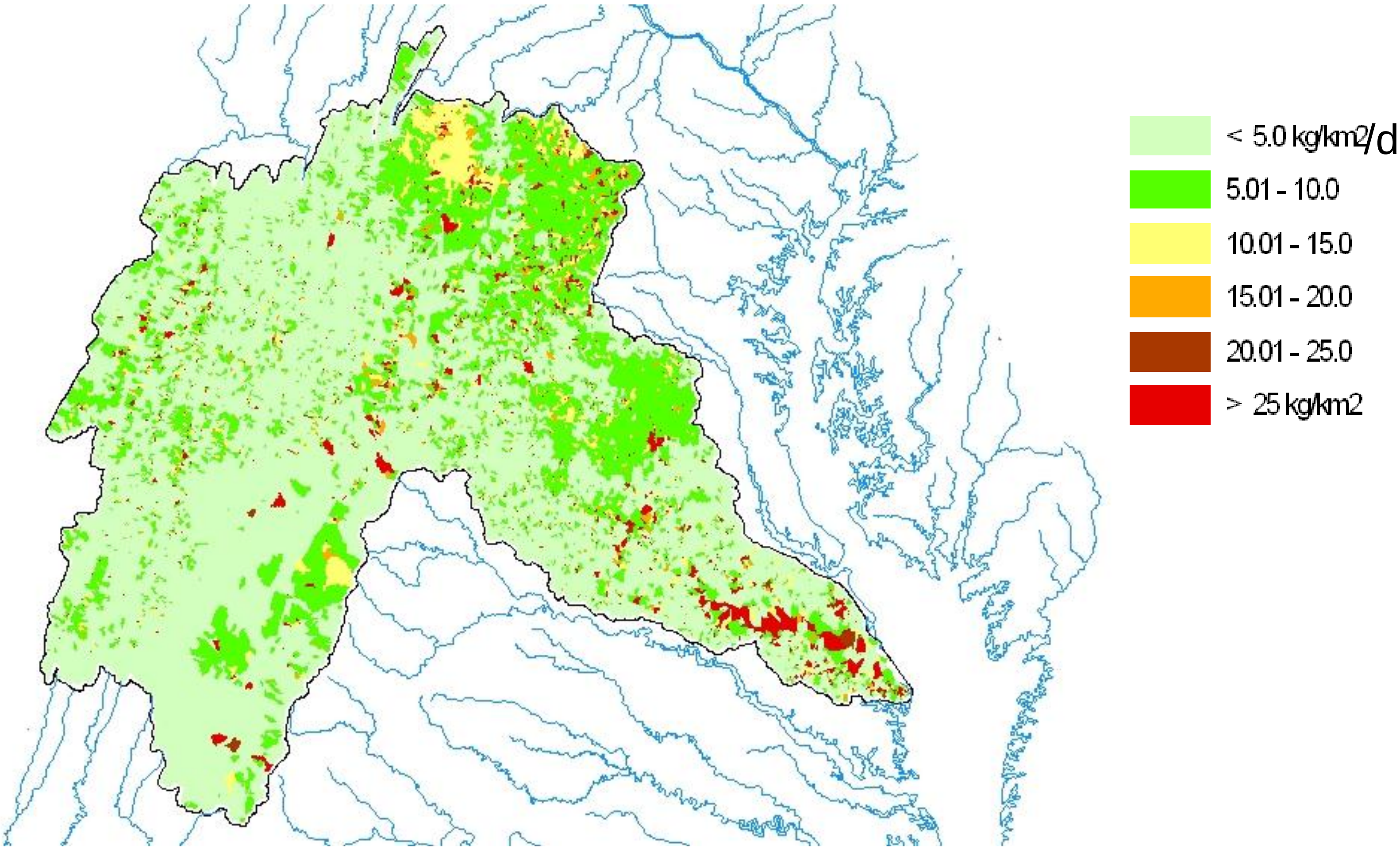
Total Nitrogen Yield (kg km^{-1} day^{-1}) Spring 2008



Total Nitrogen Yield (kg km^{-1} day^{-1})
Summer 2008



Total Nitrogen Yield (kg km^{-1} day^{-1})
Fall 2008



Potential Advantages of a Dynamic SPARROW Model

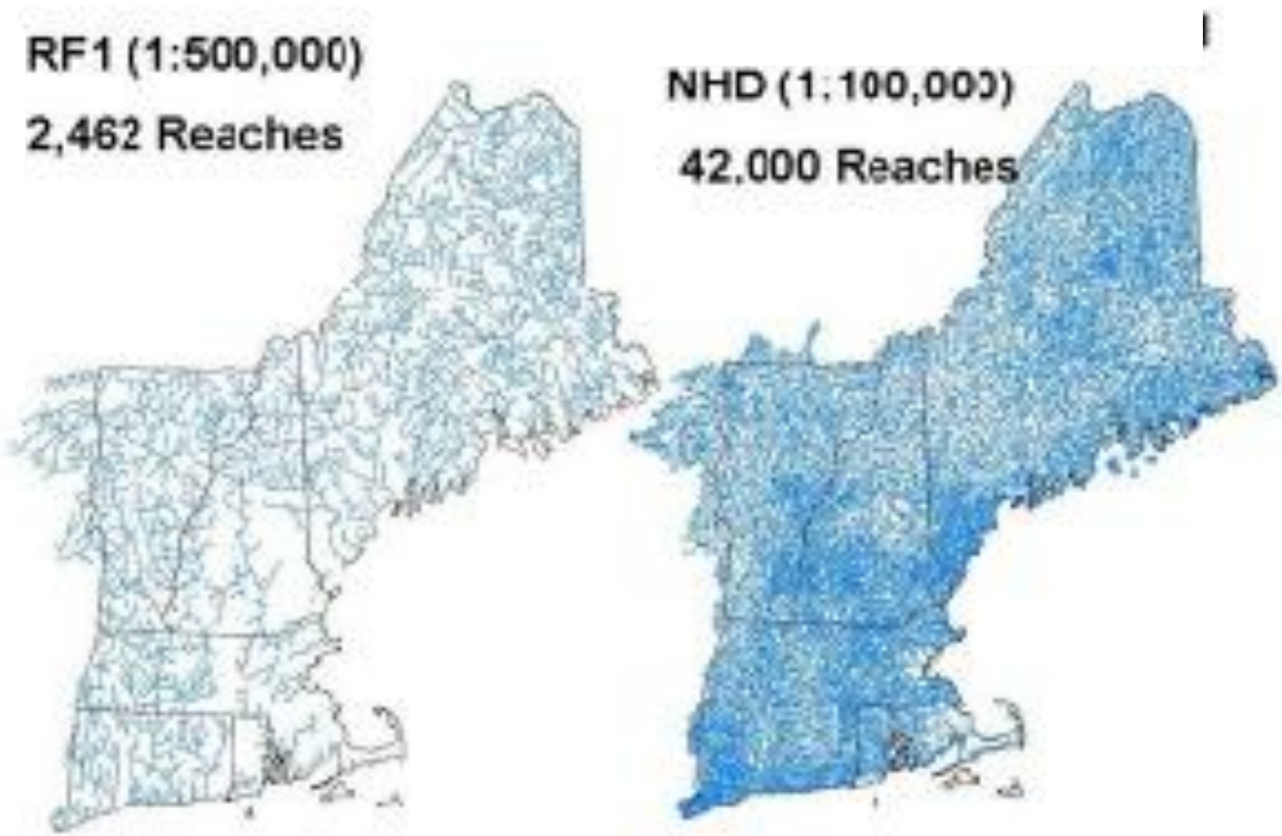
Practical (in applications)

- Interprets and predicts transitory behavior of flux given changing inputs
- Potential improvement in accuracy by removing certain assumptions and through direct use of hydrologic forcing
- Potential for calibration of SPARROW models at smaller scale due to increased number of observations.

Theoretical

- Based on a more detailed (temporal) specification of mass balance and mass residence time
- Describes role of hydrologic forcing
- Avoids “space-for-time” assumption in spatial modeling
- Introduces concept of “storage” in SPARROW modeling

Reach Networks: Two Different Scales



Presentations

Smith, R et al. “Use of MODIS Vegetation Indices in Continental and Regional-Scale Models of Reactive Nitrogen in Watersheds ”, 5th International Nitrogen Conference, 3-7 December 2010, New Delhi, India.

Nolin, AW et al. “Variations in Winter Snow and Spring Vegetation Growth: Implications for Post-fire Recovery”, AGU Fall Meeting, 6-12 Dec 2011, San Francisco, CA.

Smith, R et al. “Dynamic SPARROW Modeling of Nitrogen Flux With MODIS Vegetation Indices and Climate as Driver”, EGU General Assembly, 22-27 April 2012, Vienna, Austria.

Nolin, AW et al. “Linkages between snow cover, fire, and vegetation in mountain watersheds of the Pacific Northwest, USA”, EGU General Assembly, 22-27 April 2012, Vienna, Austria.

Publications

Ator, S.W., Brakebill, J.W., and Blomquist, J.D., 2011, Sources, fate, and transport of nitrogen and phosphorus in the Chesapeake Bay watershed—An empirical model: U.S. Geological Survey Scientific Investigations Report 2011–5167, 27 p. (Also available at http://pubs.usgs.gov/sir/2011/5167/.)

Source Contributions to Watershed Export

(Cumulative Distribution on Percent Contribution)

Source	Mean	10th	25th	50th	75th	90th	Max
Point sources*	0.55	<1	<1	<1	<1	<1	99
Urban runoff*	9.1	<1	0.2	3.3	11.0	25.1	87
Atmosphere*	19.8	1.1	5.3	13.8	28.5	47.7	99
Fertilizer*	8.6	<1	<1	1.3	11.8	31.0	85.7
Farm Animal waste*	10.5	<1	0.3	3.75	14.3	31.9	90.1
“Storage”	51.5	6.5	19.6	50.8	84.0	97.5	99

<u>Notes: </u>Estimated contributions from named sources (*) do <u>not</u> include contributions from storage.

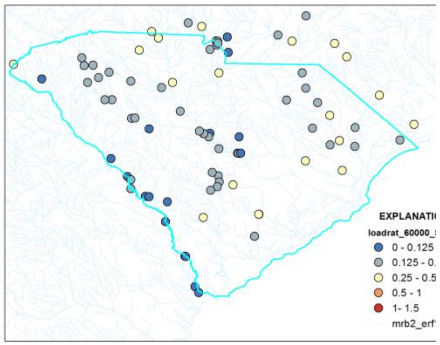
<u>Rate of “decay” of export </u>when sources are cut off is 48.5% per season on average. However, 25% of watersheds decay at less than 16% per season (i.e. < 50% per year). And 10% of watersheds decay at about 10% per season (i.e. < 34% per year).

Calibration Results (transport)

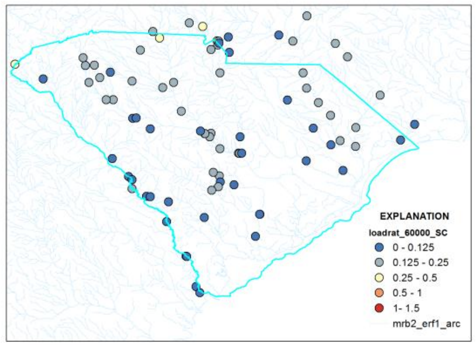
Factor/process	Units	Coefficient estimate	"t" statistic	Significance (p)
ln Runoff	ln	0.78	16.6	$< 10^{-4}$
ln delta runoff	ln	0.30	5.1	$< 10^{-4}$
ln EVI	-	-0.90	-10.1	$< 10^{-4}$
In-stream decay	days	0.015	0.56	0.58

Dynamic SPARROW modeling: pilot studies in Maryland and South Carolina

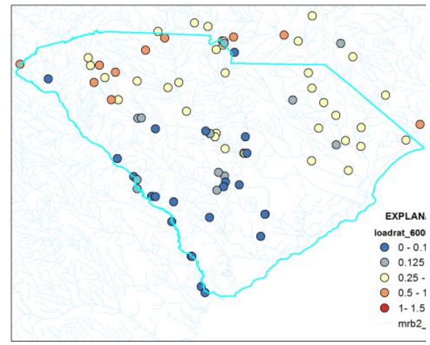
Explain the temporal and spatial pattern of stream nutrient loads



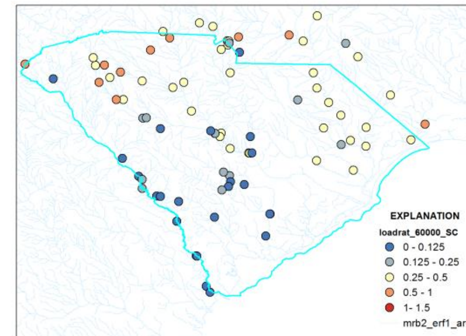
Fall 2003



Winter 2004

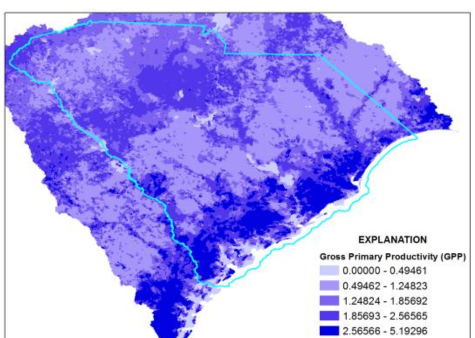


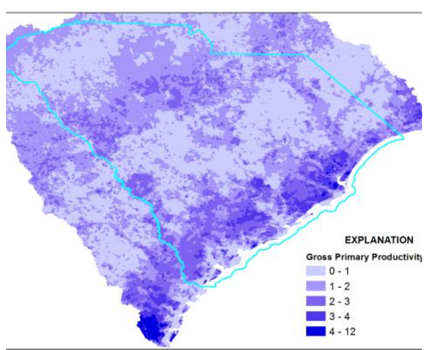
Spring 2004

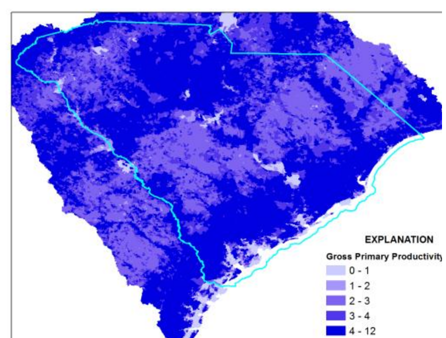


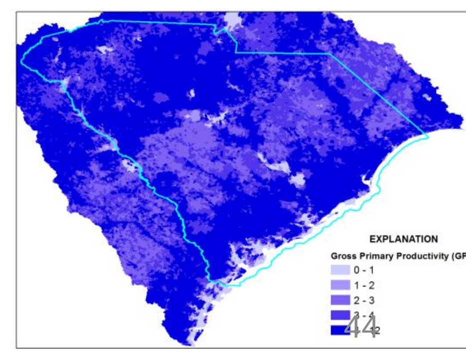
Summe r2004

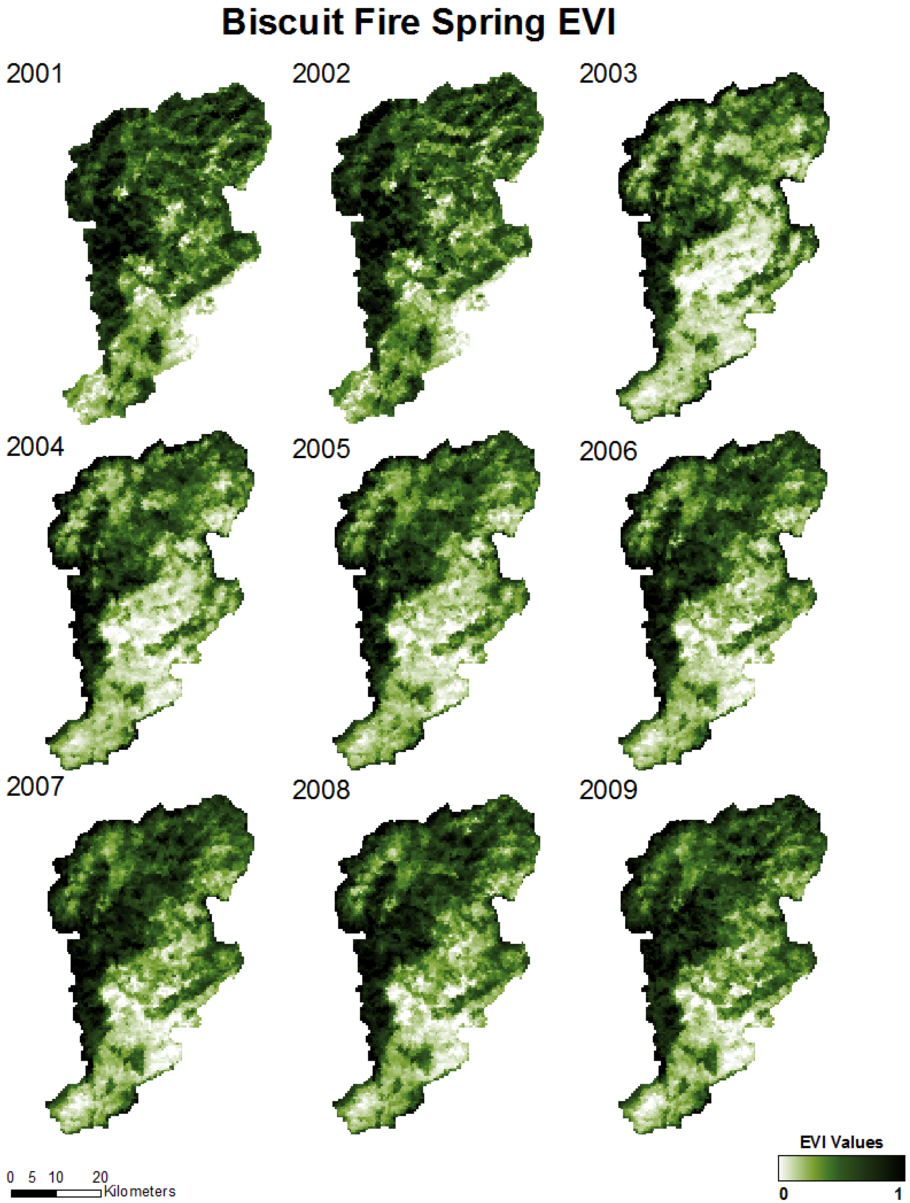
as a function of static and time-varying watershed and climate characteristics











Snow and Post-Fire Vegetation Recovery

Declining snow increases fire frequency but does snow affect post-fire vegetation regeneration?

Study area: Biscuit Fire in Southern Oregon (lg. fire in 2003)

Data: Snow frequency and Seasonal EVI

Method: Non-parametric multiplicative regression

Non-Parametric Multiplicative Regression (NPMR) used to predict post-fire biomass (EVI) based on multiple physiographic variables

Predictor Variable	Data Source
Snow frequency	MODIS 500 m
Elevation	USGS DEM 30 m
Aspect	USGS DEM 30 m
Slope	USGS DEM 30 m
Vegetation type	Landsat NLCD 30 m
Burn severity	Landsat dNBR 30 m

Pre-fire:
cross-validated $R^2 = 0.21$

Post-fire:
cross-validated $R^2 = 0.56$

Use of Enhanced Vegetation Index from MODIS

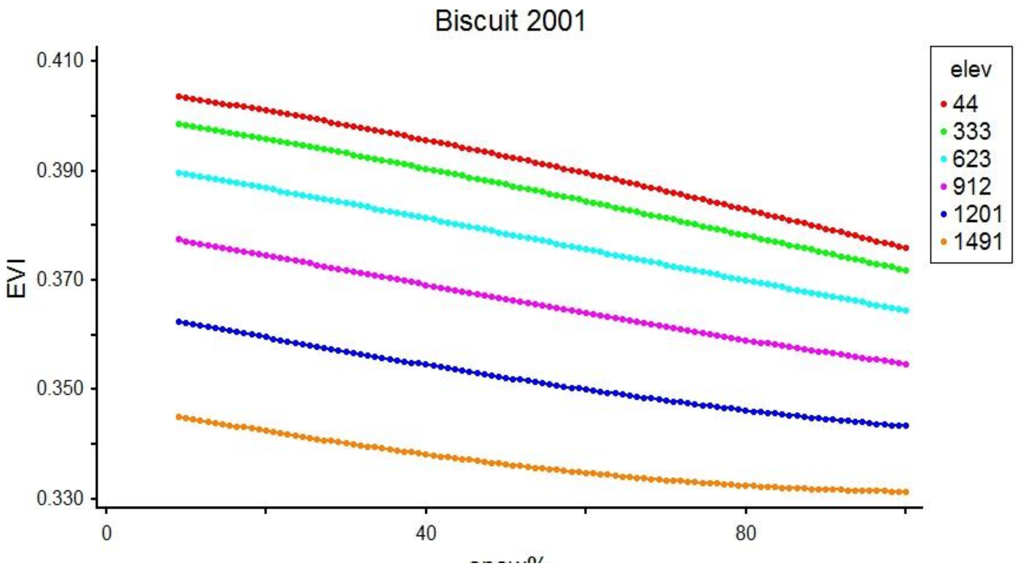
One challenge in dynamic modeling of reactive nitrogen is obtaining frequently-reported, spatially-detailed input data on the phenology of agricultural production and terrestrial vegetation.

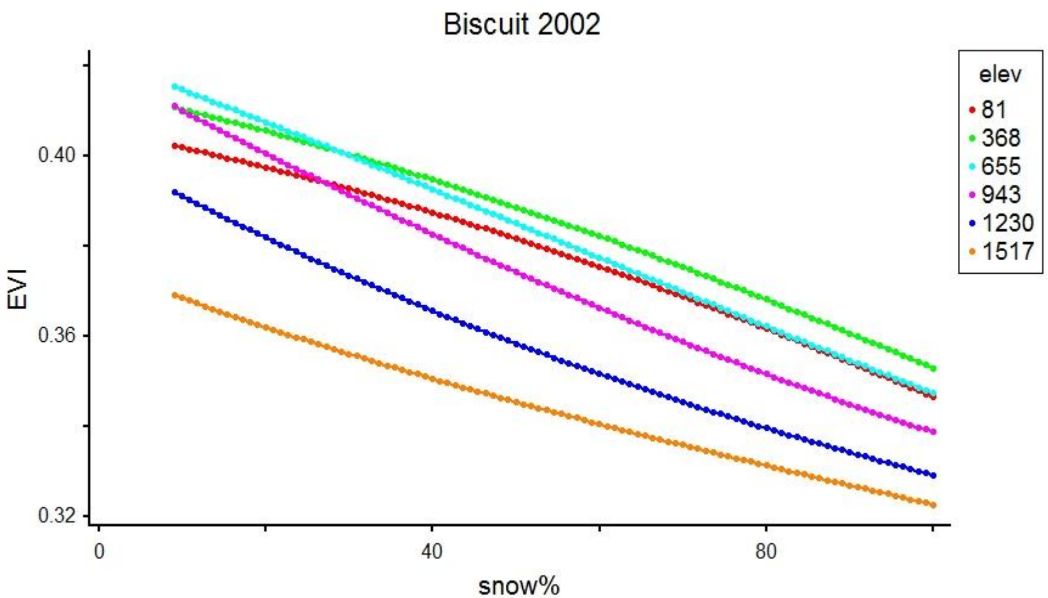
Used Enhanced Vegetation Index (EVI) data from the MODIS sensor on Terra Satellite to parameterize seasonal uptake and release of nitrogen

EVI is “enhanced” over NDVI

500-meter pixels

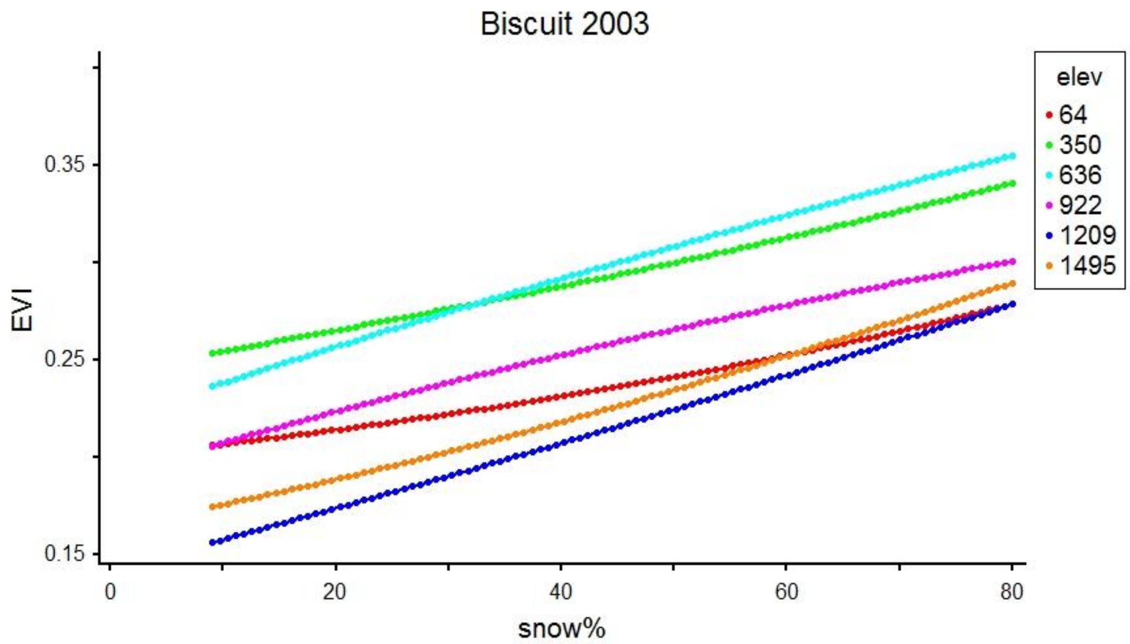
Seasonal data developed from 8-day composite data

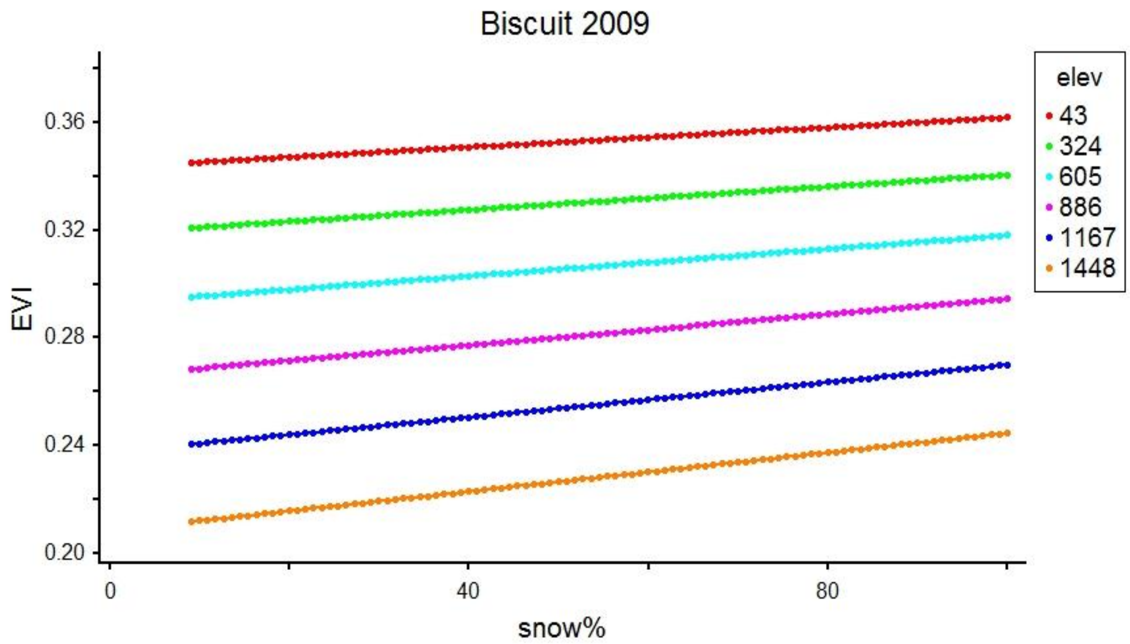




Pre-Fire:

Green biomass has a negative relationship with snowcover frequency at all elevations





Post-Fire:

Green biomass has a positive relationship with snowcover frequency at all elevations, even six years after the fire

SPARROW is now used in targeting $320 million in conservation efforts by the US Department of Agriculture, 2010-2013.

USDA NRCS
United States Department of Agriculture
Natural Resources Conservation Service

Helping People Help the Land

www.nrcs.usda.gov

Mississippi River Basin Healthy Watersheds Initiative

Overview

To improve the health of the Mississippi River Basin, including water quality and wildlife habitat, the USDA Natural Resources Conservation Service is pleased to announce the Mississippi River Basin Healthy Watersheds Initiative (MRBI). Through this new Initiative, NRCS and its partners will help producers in selected watersheds in the Mississippi River Basin voluntarily implement conservation practices and systems that avoid, control, and trap nutrient runoff; improve wildlife habitat; and maintain agricultural productivity.

The Initiative will build on the past efforts of producers, NRCS, partners, and other State and Federal agencies in the 12-State Initiative area to address nutrient loading in the Mississippi River Basin. Nutrient loading contributes to both local water quality problems and the hypoxic zone in the Gulf of Mexico. The 12 participating States are Arkansas, Kentucky, Illinois, Indiana, Iowa, Louisiana, Minnesota, Mississippi, Missouri, Ohio, Tennessee, and Wisconsin. MRBI will be implemented by NRCS through the Cooperative Conservation Partnership Initiative (CCPI), the Wetlands Reserve Enhancement Program (WREP), Conservation Innovation Grants (CIG), and other programs.

NRCS will offer this Initiative in fiscal years (FYs) 2010 through 2013, dedicating at least $80 million in financial assistance in each fiscal year. This is in addition to funding by other Federal agencies, States, and partners and the contributions of producers. The $80 million will be in addition to regular NRCS program funding in the 12 Initiative States, and will be supported with needed technical assistance.

NRCS MRBI Funding *(in millions of dollars)*

	FY 10	FY 11	FY 12	FY 13
CCPI	$50	$50	$50	$50
WREP	$25	$25	$25	$25
CIG	$5	$5	$5	$5
Total	$80	$80	$80	$80

How Will MRBI Work?

Step One: Watershed Selection

NRCS, in consultation with State Technical Committees, selected forty-one (41) 8-digit hydrologic unit code (HUC) watersheds as focus areas for the MRBI. (8-digit HUC watersheds are 250,000 to 1,250,000 acres in size). When making these selections, States considered future growth opportunities and providing opportunities for maximum program participation. States utilized a consistent watershed evaluation process that included the following information:

- Conservation Effects Assessment Project (CEAP) data.
- Spatially Referenced Regression On Watershed (SPARROW) attributes. SPARROW is a statistically based U.S. Geological Survey (USGS) modeling approach that attempts to explain in-stream measures of water quality in relation to upstream sources.
- State-level nutrient reduction strategies and priorities.
- State-level water quality data.
- Monitoring and modeling of nitrogen and phosphorous management

Step Two: Request for Proposals

NRCS will announce a Request for Proposals (RFP) for the MRBI. The request will seek proposals to utilize the Cooperative Conservation Partnership Initiative (CCPI) and the Wetlands Reserve Enhancement Program (WREP) as the foundation for MRBI to leverage investment from non-Federal sources and ensure coordination of NRCS efforts with other Federal, State, Tribal, and local efforts.

The RFP will allow eligible partners to submit proposals addressing the conservation objectives to be achieved in one or more 12-digit HUC subwatersheds within the designated 8-digit focus area or areas. All proposals will be submitted to the NRCS Chief and copied to the appropriate State Conservationist(s). For information on the RFP and a list of focus area watersheds, please go to www.nrcs.usda.gov/programs/mrbi/mrbi.html.

Cooperative Conservation Partnership Initiative

CCPI offers a statutory (2008 Farm Bill) funding mechanism for targeting resources on a watershed basis across three programs: the Environmental Quality Incentives Program (EQIP), the Wildlife Habitat Incentive Program (WHIP), and the Conservation Stewardship Program (CSP).

Under MRBI-CCPI, NRCS enters into multi-year agreements with eligible partner organizations to use EQIP, WHIP, and/or CSP to address conservation priorities related to agriculture and nonindustrial private forest land. The MRBI-CCPI emphasizes a "systems approach" to address water quality resource concerns. A cornerstone of this approach is to use screening and ranking systems to focus program support on participants who will implement a system of practices, that is, multiple practices and management techniques that work together to

S, the amount of contaminant in storage, is a “latent” variable - i.e. a state variable that can not be observed or measured.

However, since **S = L/r** , we can write

$$\mathbf{L_t = I\, r_t/r' \; [\, 1 - \exp(-r'\Delta t)\,] \; + \; L_0\, r_t / r_0 \exp(-r'\Delta t)} \qquad \mathbf{(3)}$$

<u>Definitions:</u>

I = rate of input of contaminant from a specific source to watershed (m/t)

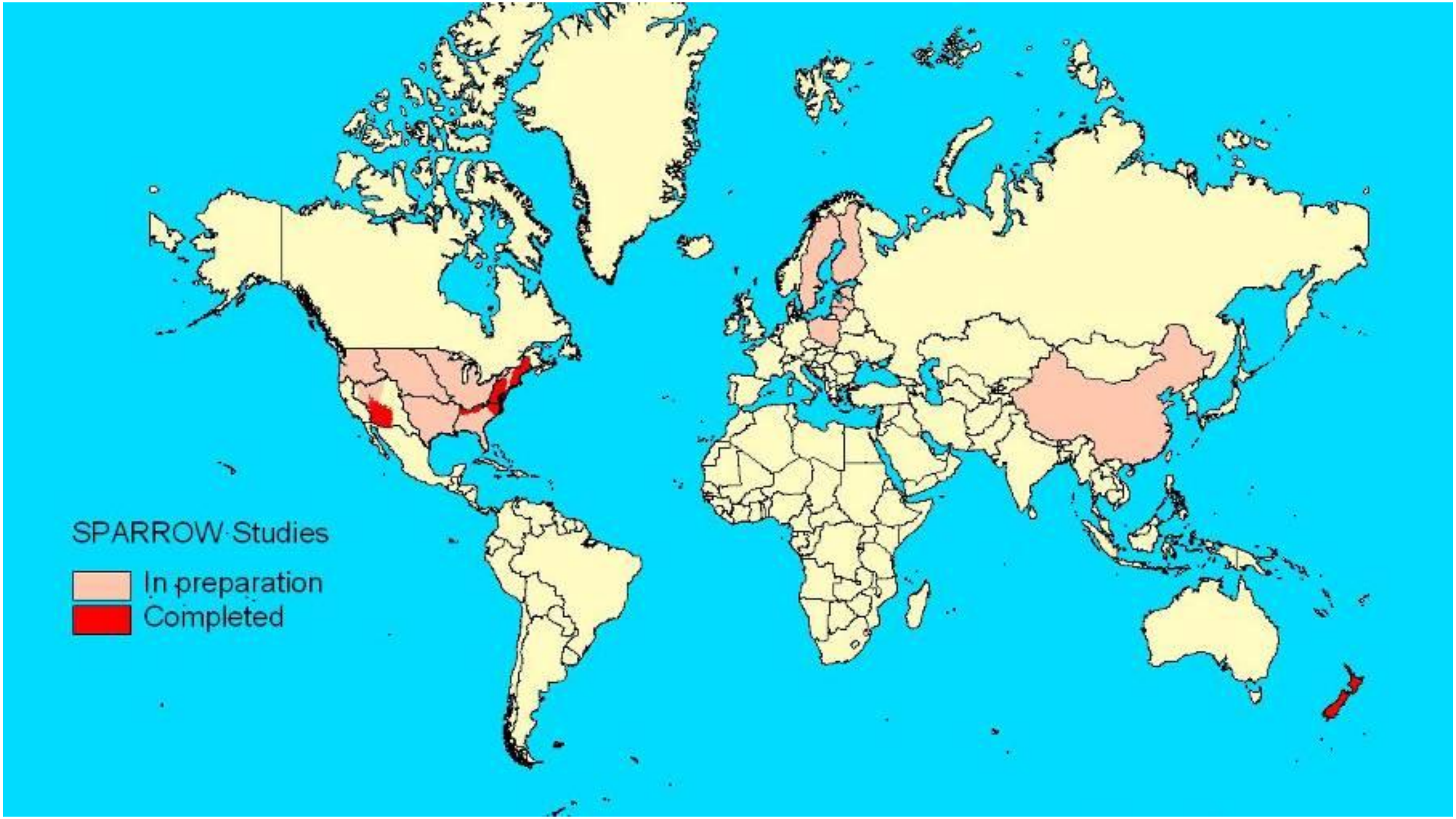
S = mass of contaminant in “active” land-to-water storage (m)

L = **r S** = contaminant flux from storage to stream, where **r** is 1st order rate coefficient

k S = instantaneous removal rate from storage to all places other than stream (e.g. atmosphere); **k** is 1st order rate coefficient

the subscripts **0** and **t** denote the beginning and end of a time interval **Δt;** and **r’** (**=** $\mathbf{k_{av}+r_{av}}$) is the total rate coefficient for removal from storage based on the average values of **r** and **k** over the interval Δt

SPARROW Regional and International Studies



What is SPARROW?

SPAtially Referenced Regressions On Watershed Attributes

- Hybrid empirical / mechanistic watershed WQ model
- Explains spatial variation in WQ data from monitoring networks
- Spatially detailed predictions
- Accounts for non-conservative
- Maintains mass balance in stream/river network
- Calibration through statistical optimization
- Predictions accompanied by error estimates

SPARROW's Reach-Scale Mass Balance
Reach network relates watershed data to monitored loads

$$LOAD_i = \left\{ \sum_{j\in J(i)} \left[\sum_{n=1}^{N} S_{n,j}\beta_n \exp(-\alpha' Z_j) \right] \prod_m \exp(-\delta_m^s T_{i,j,m}) \prod_l 1/(1+\lambda^r q_{i,j,l}^{-1}) \right\} \exp(\varepsilon_i)$$

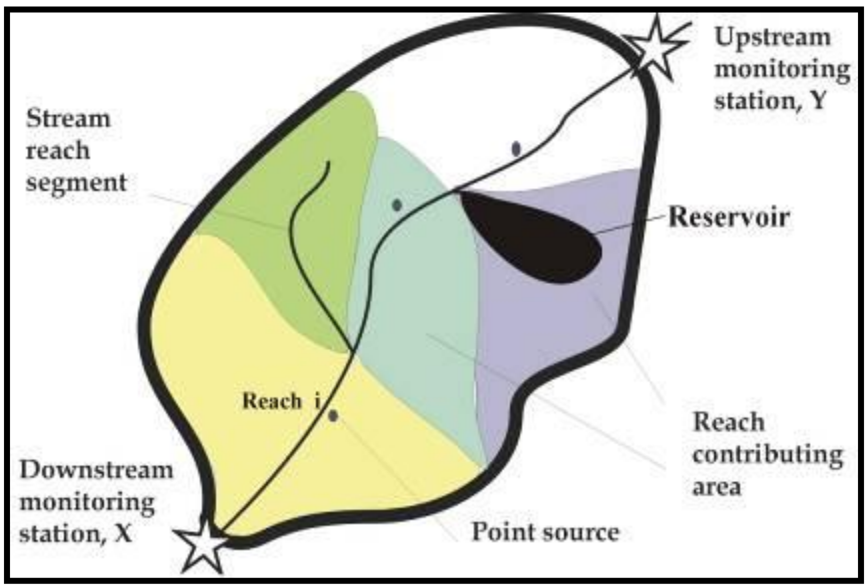
Monitored Stream Load

Sources

Land-to-water transport

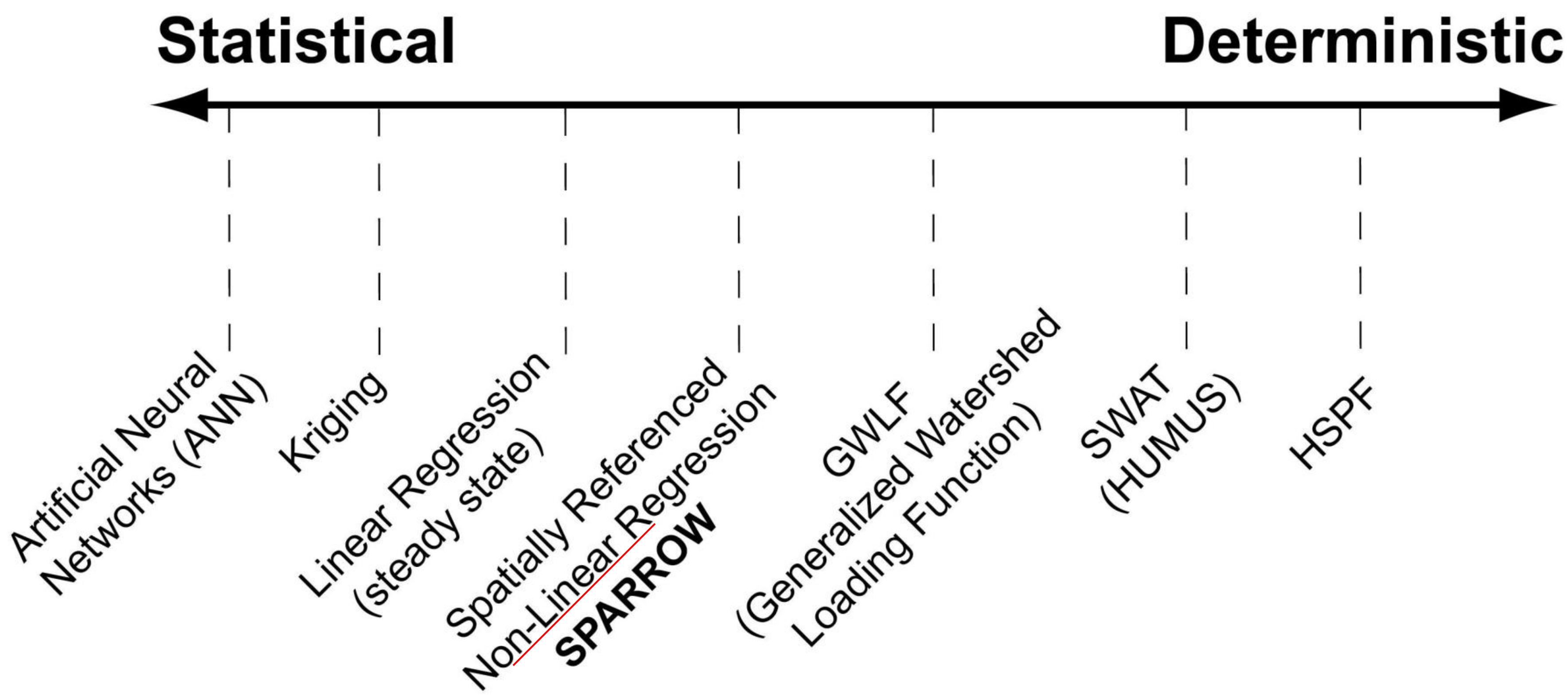
Aquatic transport

Error



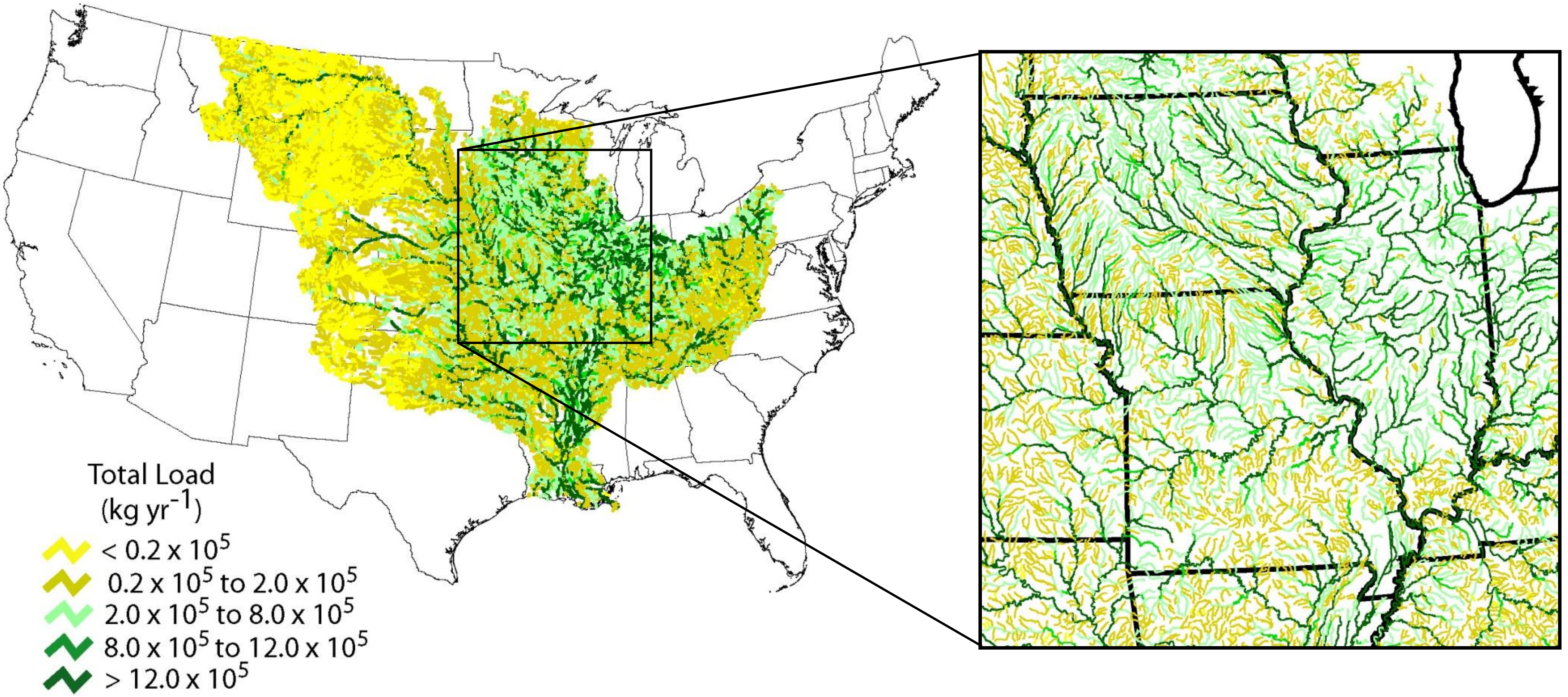
- Spatial reference frame is stream network, coupled to DEM
- Fundamental spatial element is stream reach and associated incremental drainage area
- SPARROW estimates the optimal set of rate coefficients that balance material mass (source inputs, stream loads, and storage/loss)

Position of SPARROW in the Watershed Model Continuum

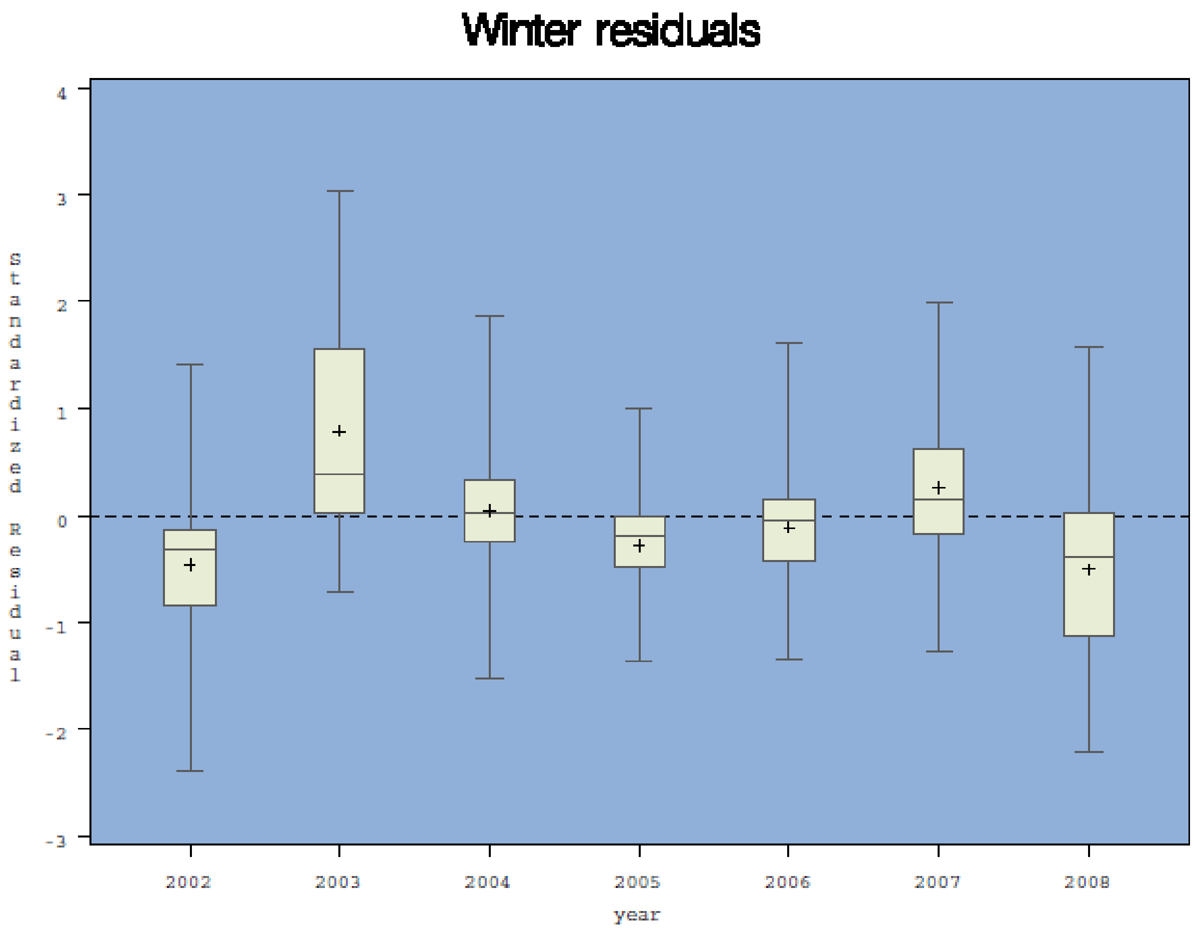


Reach Network at Two Different Scales

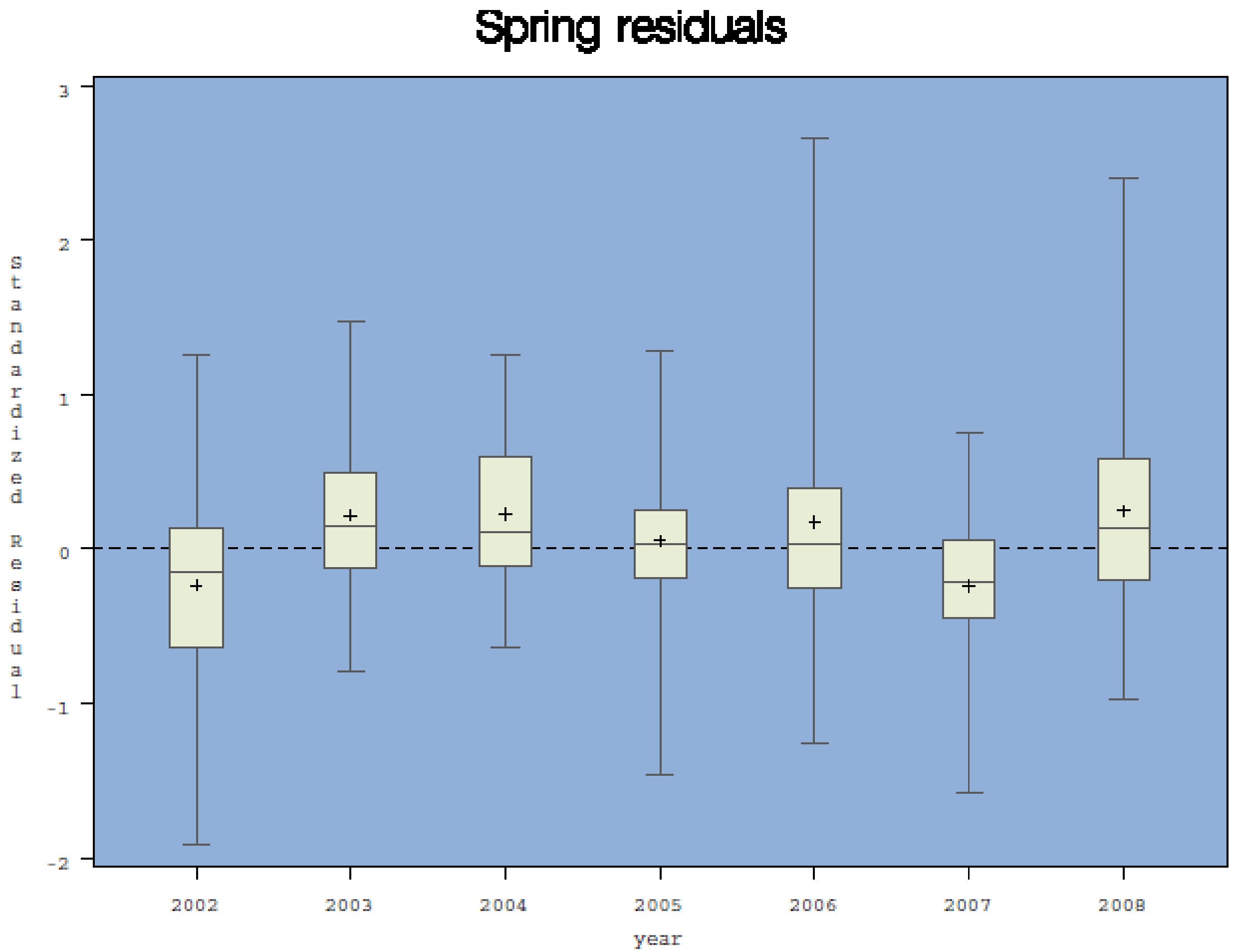
Insert E2rf1 (65,000) and NHD (2.5 mil)



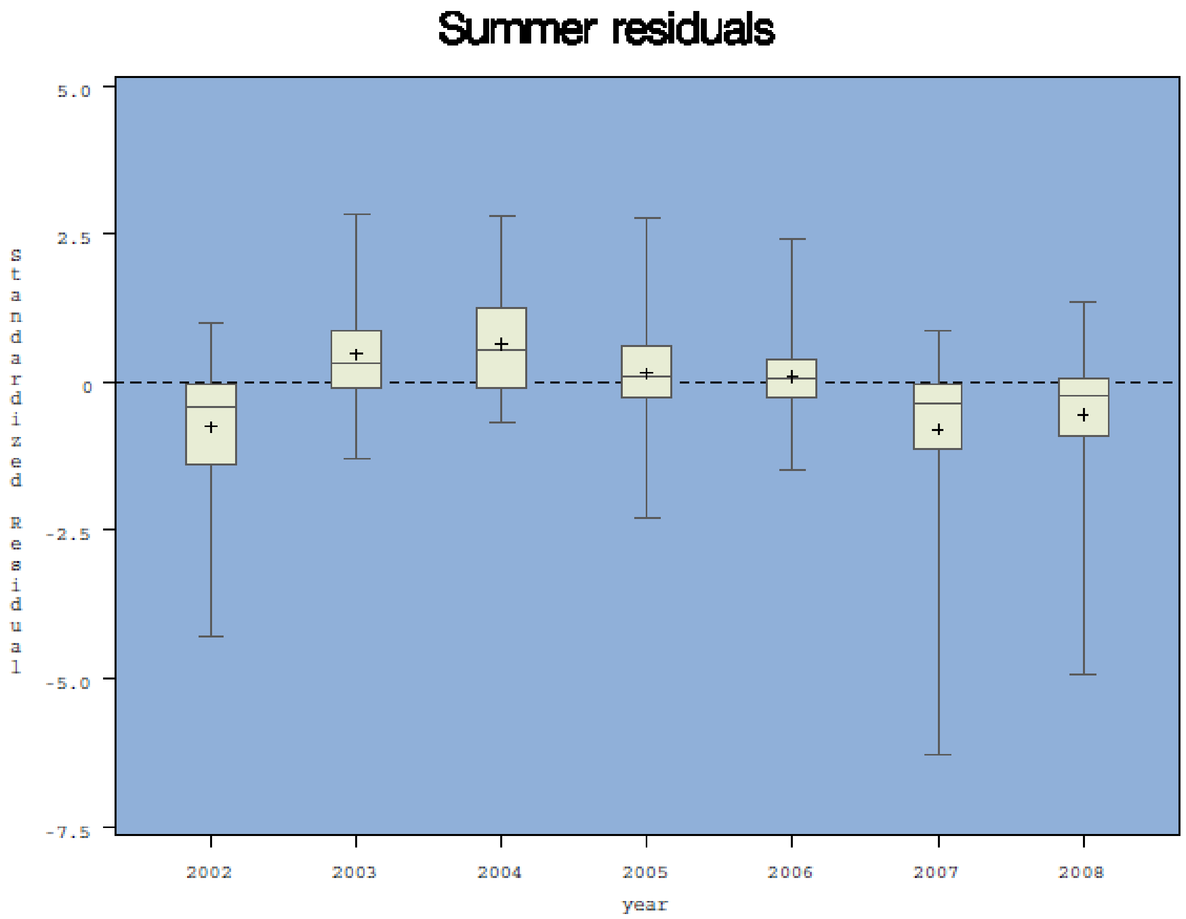
Seasonal Accuracy



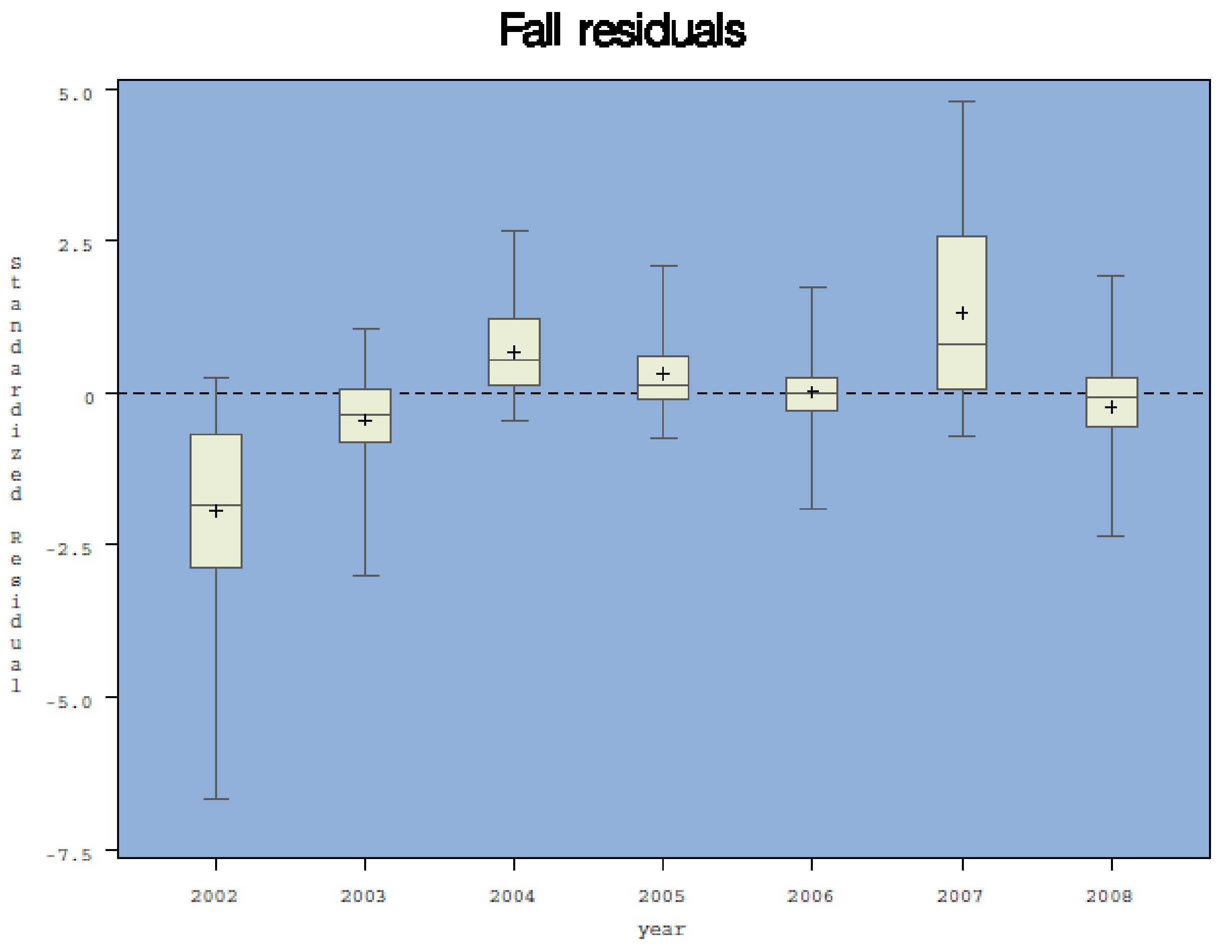
Seasonal Accuracy

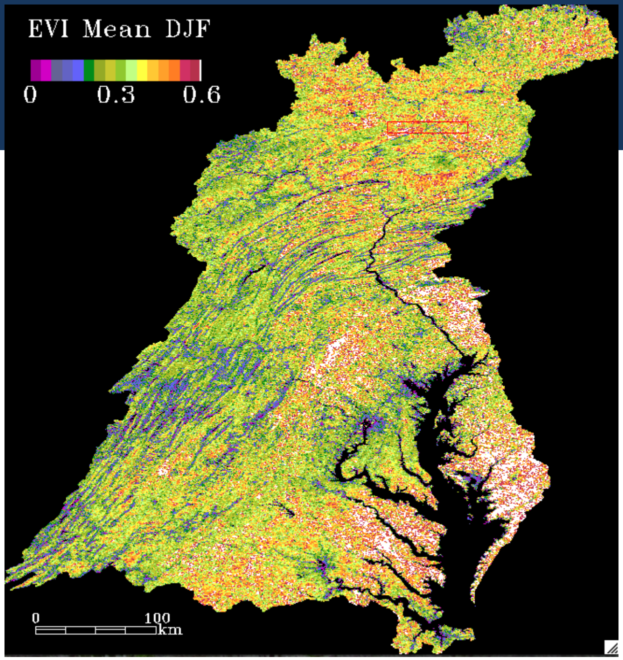


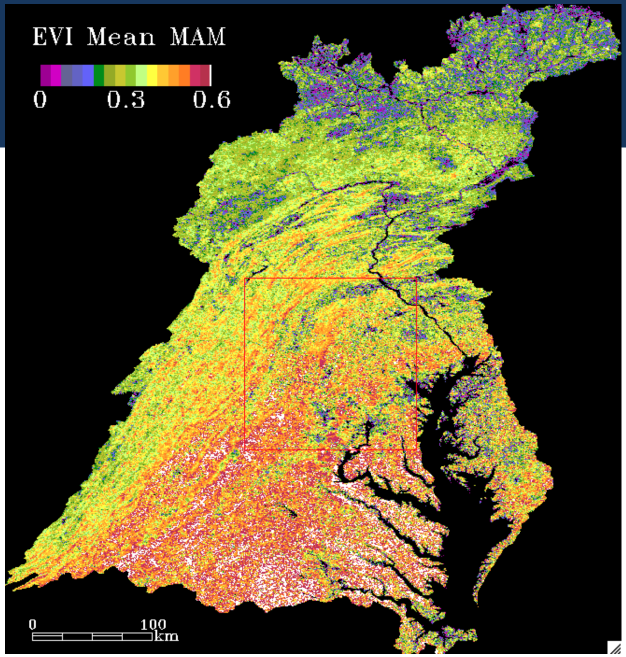
Seasonal Accuracy

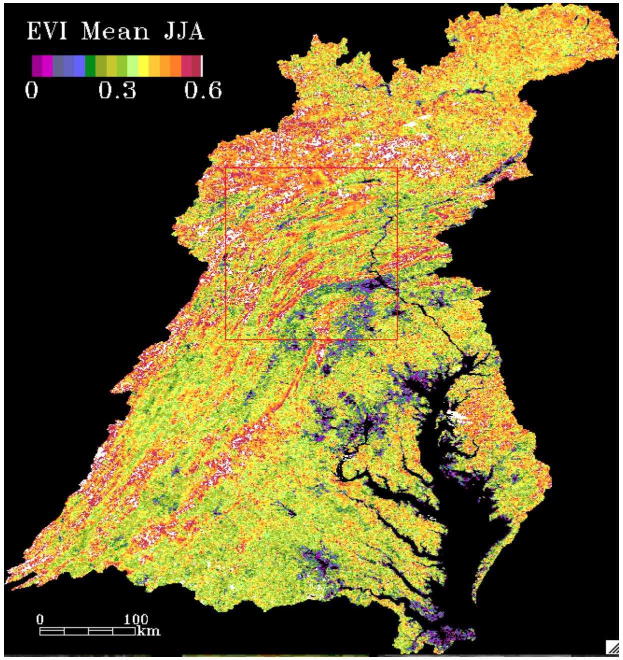


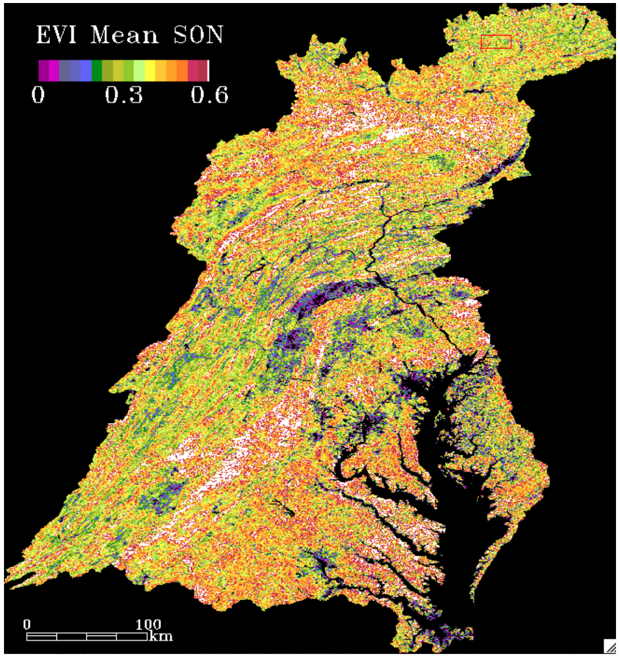
Seasonal Accuracy




EVI Mean DJF
0 0.3 0.6
0 100 km

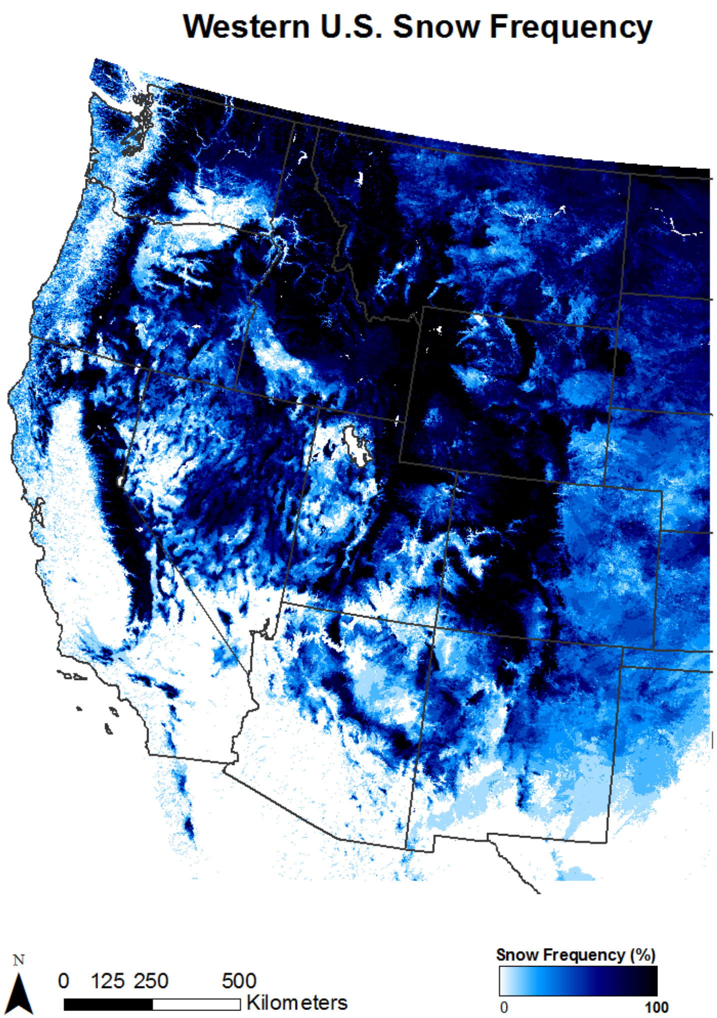

EVI Mean MAM
0 0.3 0.6
0 100 km


EVI Mean JJA
0 0.3 0.6
0 100 km


EVI Mean SON
0 0.3 0.6
0 100 km

SPARROW Model Applications

- Geographic Description of Water Quality - Targeting
- *Forecasting Effects of Changes in Contaminant Sources (e.g. TMDLs) and Other Basin Conditions
- Hypothesis Testing - Research
- Design of Monitoring Networks



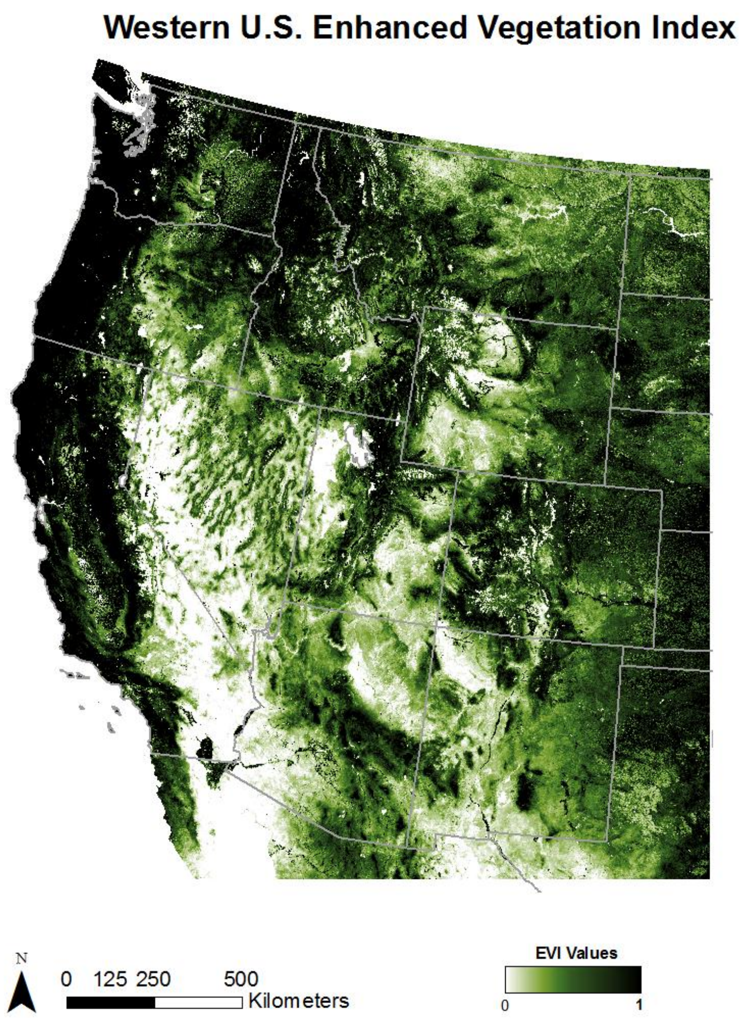
- Snow-covered area from Moderate Resolution Imaging Spectroradiometer (MODIS); 8-day, 500-m
- Compute the frequency of snow cover within each 3-month period (OND, JFM, AMJ, JAS)
- WY 2001-2009

$$\boxed{\text{snow freq} = N_{snow} / N_{observations}}$$

Enhanced Vegetation Index (EVI) is sensitive to green biomass

$$\boxed{EVI = G\frac{r_{NIR} - r_{red}}{r_{NIR} + \left(C_1 r_{red} - C_2 r_{blue}\right) + L}}$$

ρ_{red} = Reflectance in MODIS red channel
ρ_{NIR} = Reflectance in MODIS NIR channel
ρ_{blue} = Reflectance in MODIS blue channel
C_1 = Atmospheric resistance red correction coefficient (C_1 = 6)
C_2 = Atmospheric resistance red correction coefficient (C_2 = 7.5)
L = Canopy background brightness correction factor (L = 1)
G = Gain factor (G = 2.5)



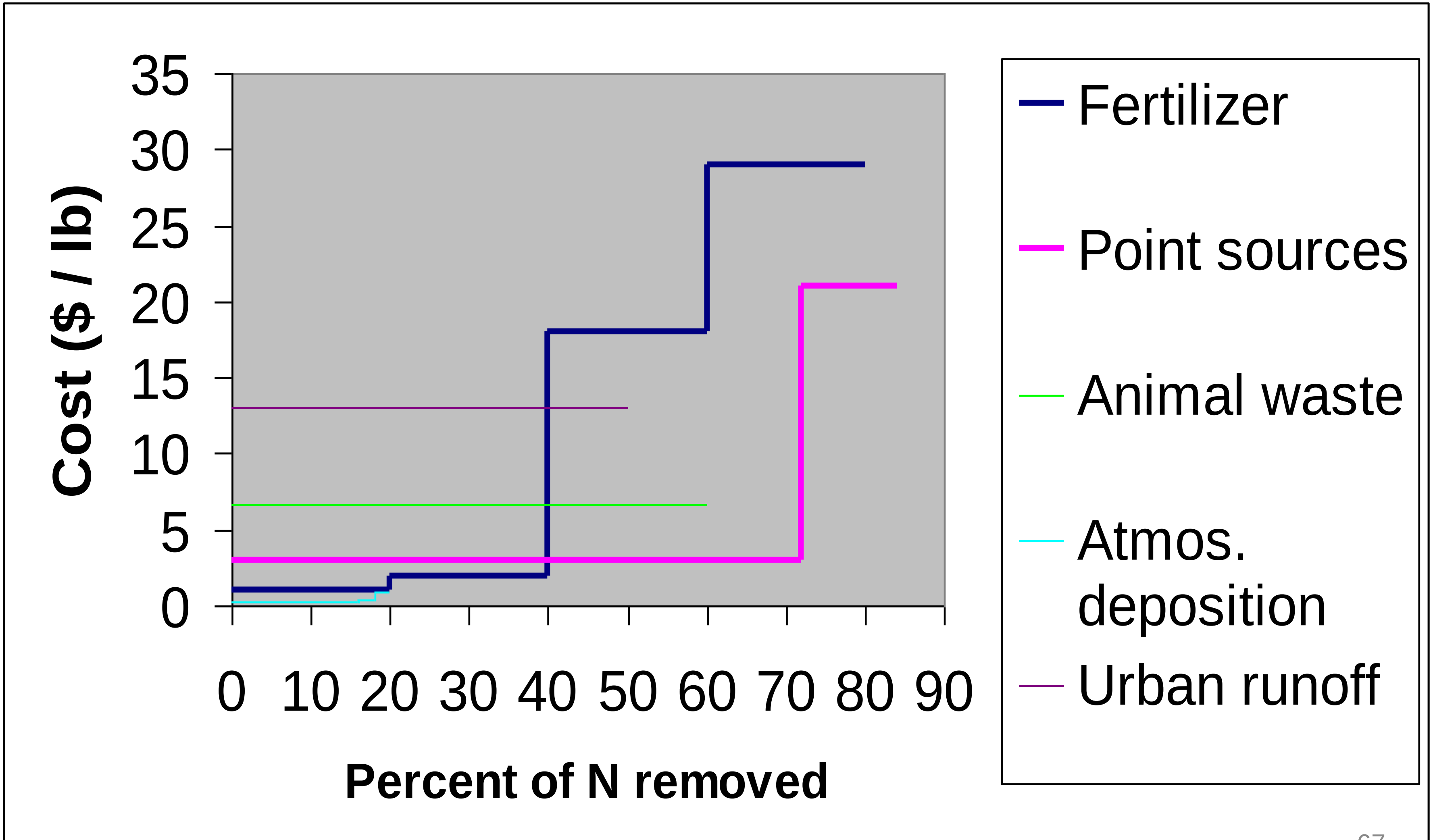
- MODIS surface reflectance, 8-day, 500-m
- Compute median EVI for each 3-month period (OND, JFM, AMJ, JAS)
- WY 2001-2009

Tools: (2) MODIS Data
Enhanced Vegetation Index (EVI)

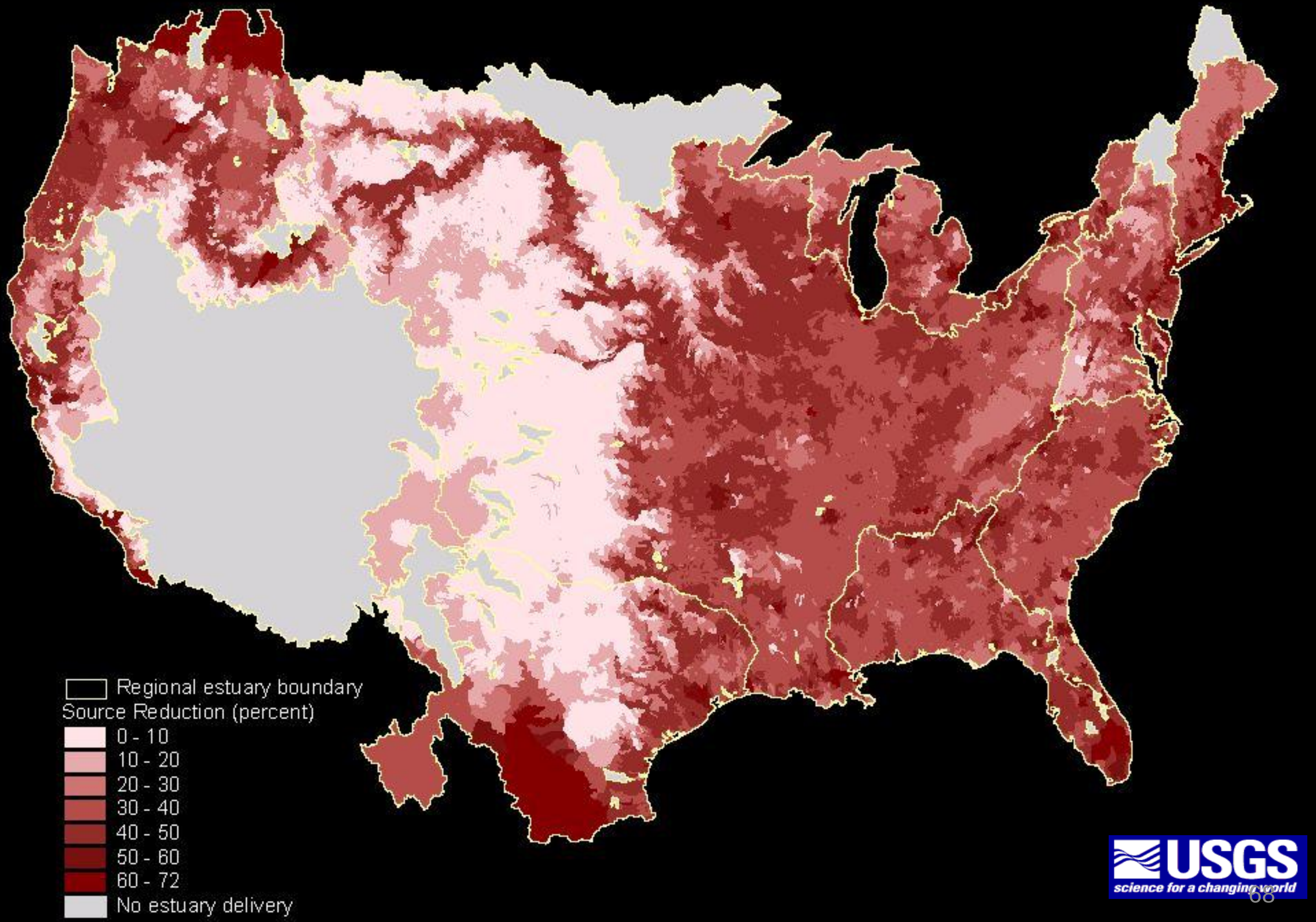
DICK and John, pls add here GPP and other data?

- Index of vegetation density on a scale from zero to one (like NDVI, but corrected for distortion and saturation)
- 8-day frequency
- 250-meter resolution

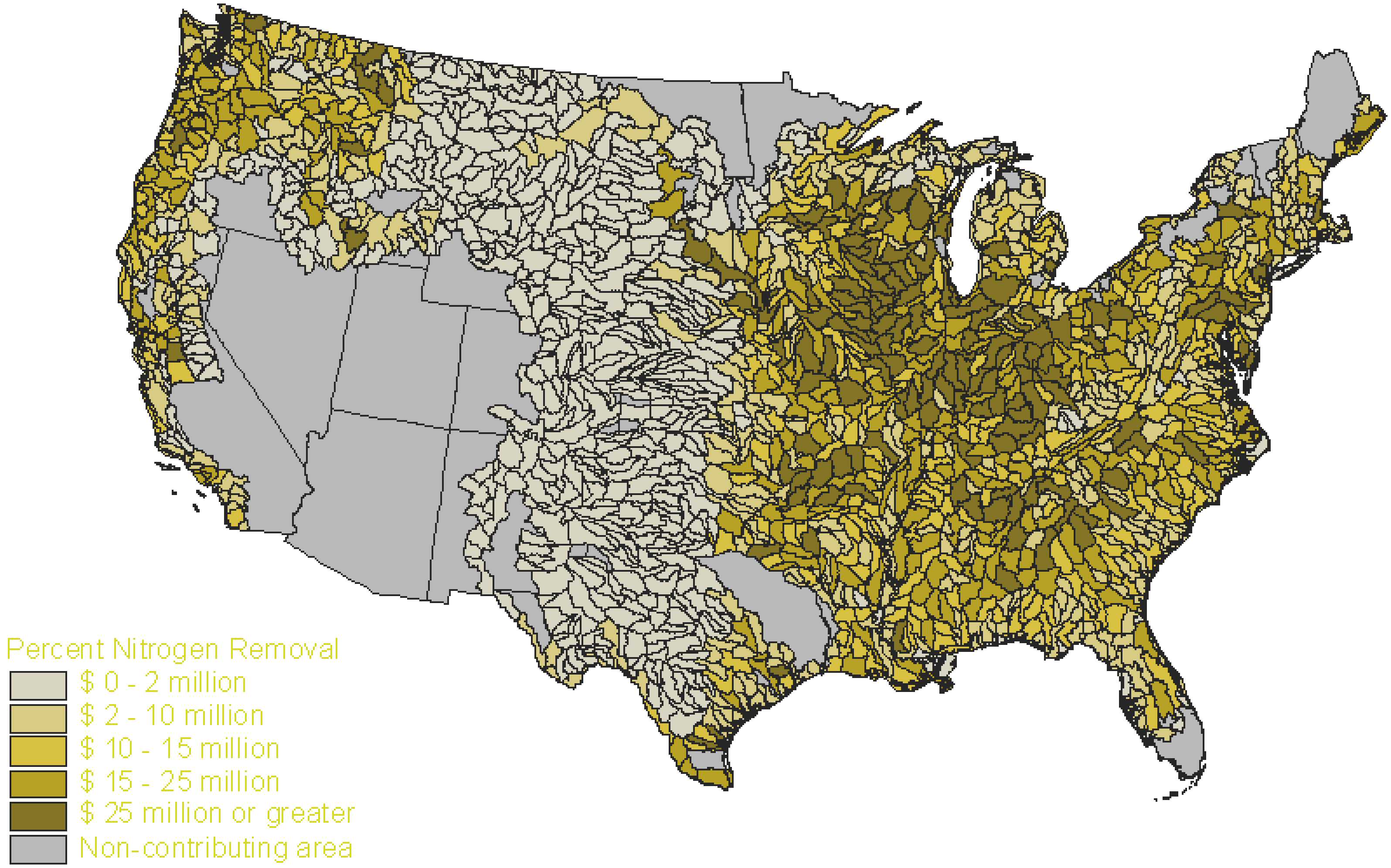
Marginal Costs of Nitrogen Source Reductions



Optimal Percent Reduction to Achieve a 40 Percent Reduction in TN Loadings to each Regional Estuary

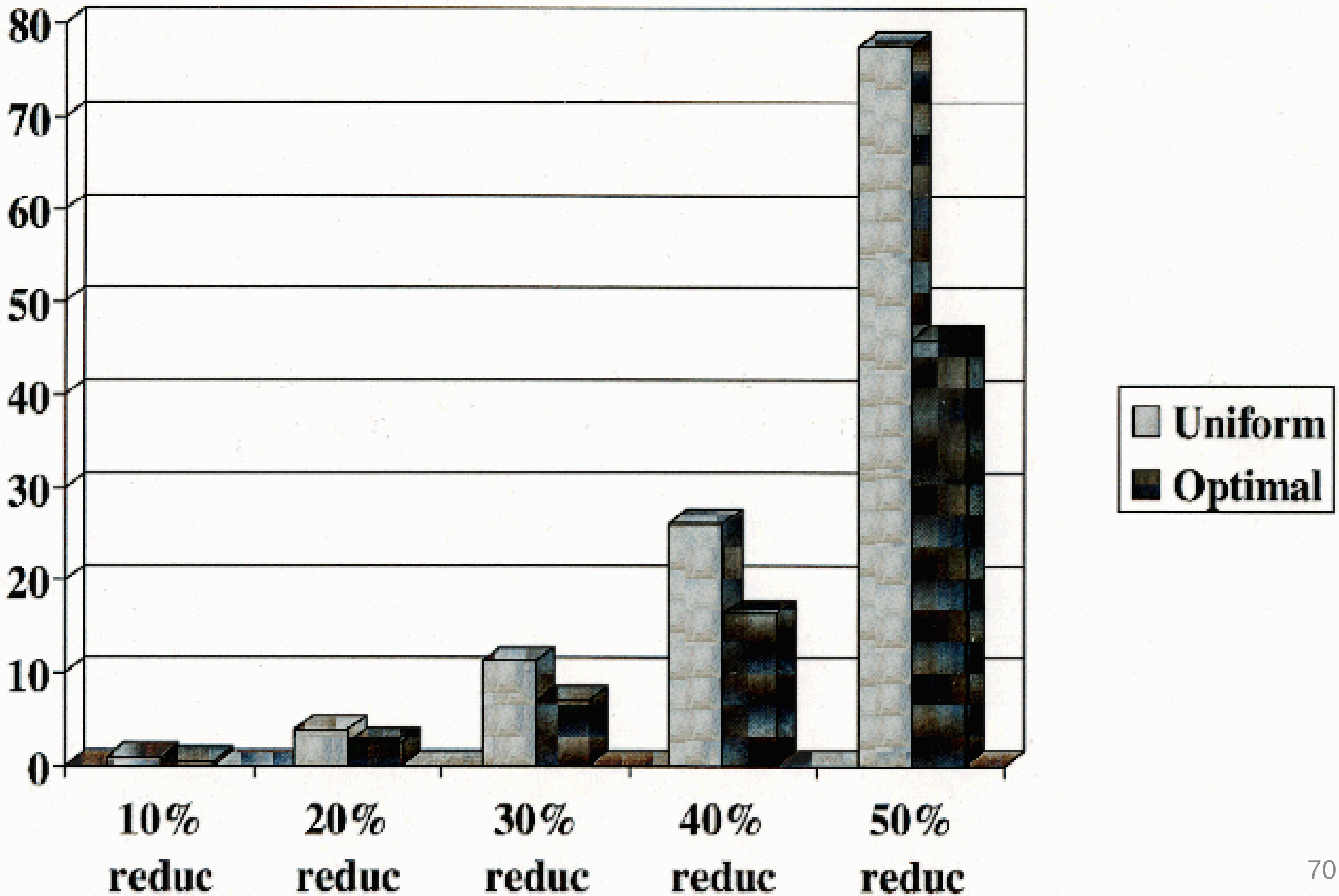


Cost of Optimal Nitrogen Removal in Hydrologic Units to Obtain a 40 Percent Reduction at Estuaries

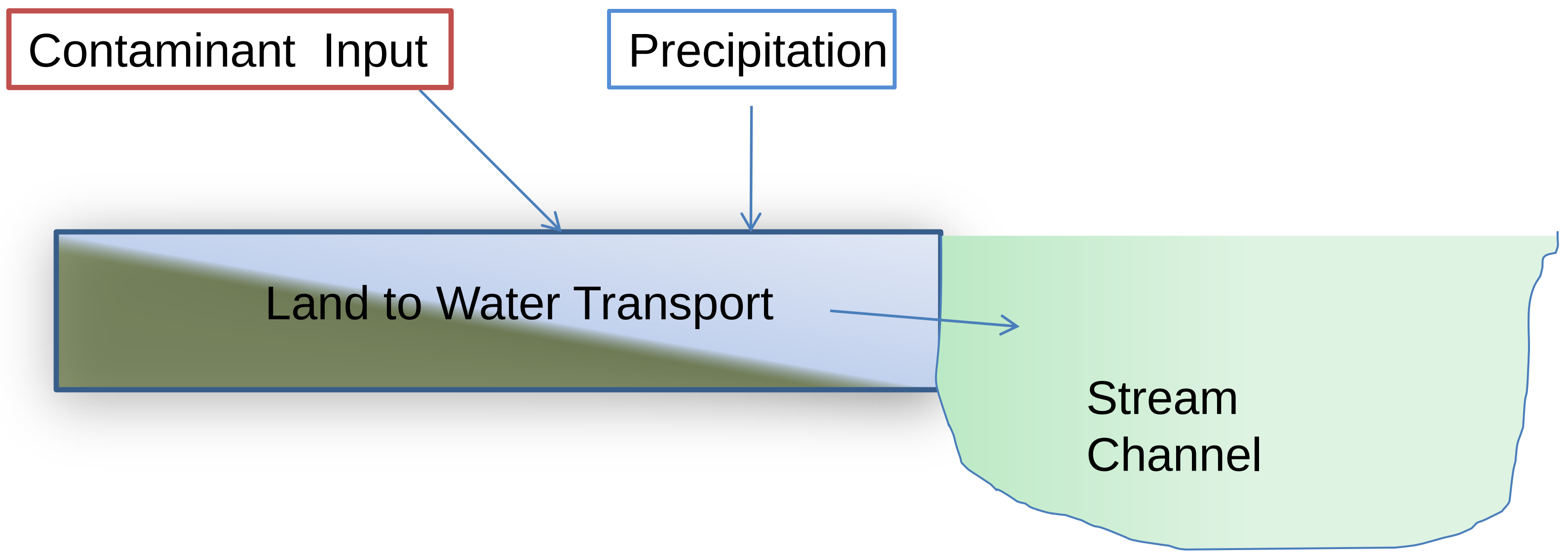


Cost of Nitrogen Control ($B/yr)

National Totals



An essential mechanism of dynamic behavior in watersheds is temporary "storage". Reservoirs may be either hydrologic or biogeochemical.



Calibration Results (transport)

Factor/process	Units	Coefficient estimate	"t" statistic	Significance (p)
ln Runoff	ln	0.78	16.6	$< 10^{-4}$
ln delta runoff	ln	0.30	5.1	$< 10^{-4}$
ln EVI	-	-0.90	-10.1	$< 10^{-4}$
In-stream decay	days	0.015	0.56	0.58

In a conventional (steady-state) SPARROW model, contaminant material from “sources” has an unknown mass and residence time in the “land-to-water” phase. In short, “storage” is unknown.